# AUSTROADS TEST METHOD AGPT/T121

# Shear Properties of Polymer Modified Binders (ARRB Elastometer)

## Commentary

### Preface

This test method was prepared by the Bituminous Surfacings Working Group (BSWG) working on behalf of the Austroads Pavements Task Force (PTF). Representatives of Austroads, ARRB Group and the Australian Asphalt Pavement Association (AAPA) have been involved in the development and review of this test method.

Polymer modified binders (PMBs) exhibit complex rheological behaviour and, consequently, simple viscometers do not provide a satisfactory measure of their viscous and elastic behaviour. ARRB Group's elastometer determines several performance related properties on PMBs and other complex binders.

The instrument operates by axially shearing an annular sample of material between two concentric cylinders to a pre-set strain level using a controlled strain rate (loading phase). At this point, the load is removed and the amount of strain recovery is measured with time (recovery phase).

During the loading phase, both sample displacement and the force on the sample are measured. The force recorded at a sample strain of 0.06 is used to calculate consistency 6%. The maximum force achieved at the end of the loading phase (normally at a sample strain of 1.0) is used to calculate the consistency and stiffness of the material. During the recovery phase, the elastic recovery (which corresponds to the recovered strain, expressed as a percentage of the original strain) is measured after various times of recovery (e.g. 100 s and 300 s).

### Scope

This test method sets out the procedures for the determination of consistency, consistency 6%, stiffness and elastic recovery of polymer modified binders (ARRB elastometer), under specific conditions of deformation, using the elastometer developed by ARRB Group.

### Further development

This test method is under development and some changes in the test parameters may occur in the future.

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# 1. References

The following documents are referred to in this method:

**Austroads test methods**

| | |
|---|---|
| AGPT/T101 | *Method of sampling polymer modified binders, polymers and crumb rubber.* |
| AGPT/T102 | *Protocol for handling polymer modified binders in preparation for laboratory testing.* |
| AGPT/T190 | *Specification framework for polymer modified binders.* |

# 2. Apparatus

The required apparatus is as follows:

(a) ARRB elastometer – A schematic diagram of the elastometer is shown in Figure 2.1.

(b) Computer controller – The elastometer can be controlled, and results recorded, using two different versions of the software. The software version used depends on the configuration of the elastometer. Elastometers which are connected to a computer using a 25 pin serial plug use the original Windows 3.1 based operation software. Those which are connected to a computer using a USB-based system use the new Windows 7 based operation software. The computer requirements for each type of software are listed below:

   1. Original operation software: A PC with the minimum requirements of a 486/33 processor with 8 MB of RAM and a 540 MB hard disk operating under Windows 3.1.
   2. New operation software: A PC with the minimum requirements of an Intel Core 2 duo processor with 4 GB RAM and a 150 GB hard disk operating under Windows 7.

(c) Constant temperature bath – Capable of maintaining the temperature to within ± 0.1 °C, such as a Lauda Model MS 20, or equivalent. The water bath must be of suitable dimensions to satisfactorily accommodate the elastometer and provide a water depth of 135 mm for immersion of the sample. The bath must be fitted with a perforated baffle to minimise water turbulence around the sample.

(d) Sample moulds – Consisting of an inner and an outer cylinder, assembly base, Teflon sheet gasket and locknut. The cylinders are accurately machined with the inner cylinder trimmed to an exact mass, so that it can be used interchangeably with replacements without the need for rebalancing the instrument.

(e) Figure 2.2 shows the three different types of mould configurations used with the elastometer. Moulds designated as A, B and C have been developed to cover a range of testing requirements.

Mould A is the standard mould routinely used for testing consistency and consistency 6% (at 60 °C) and mould C is used for testing stiffness (at 15 °C and 25 °C). Mould B can be used when test results are required at 60 °C on softer binders, such as S10E, S35E and A25E grade PMBs (Austroads AGPT/T190). Details of the moulds are given in Table 2.1.

**Figure 2.1: Schematic diagram of the elastometer**

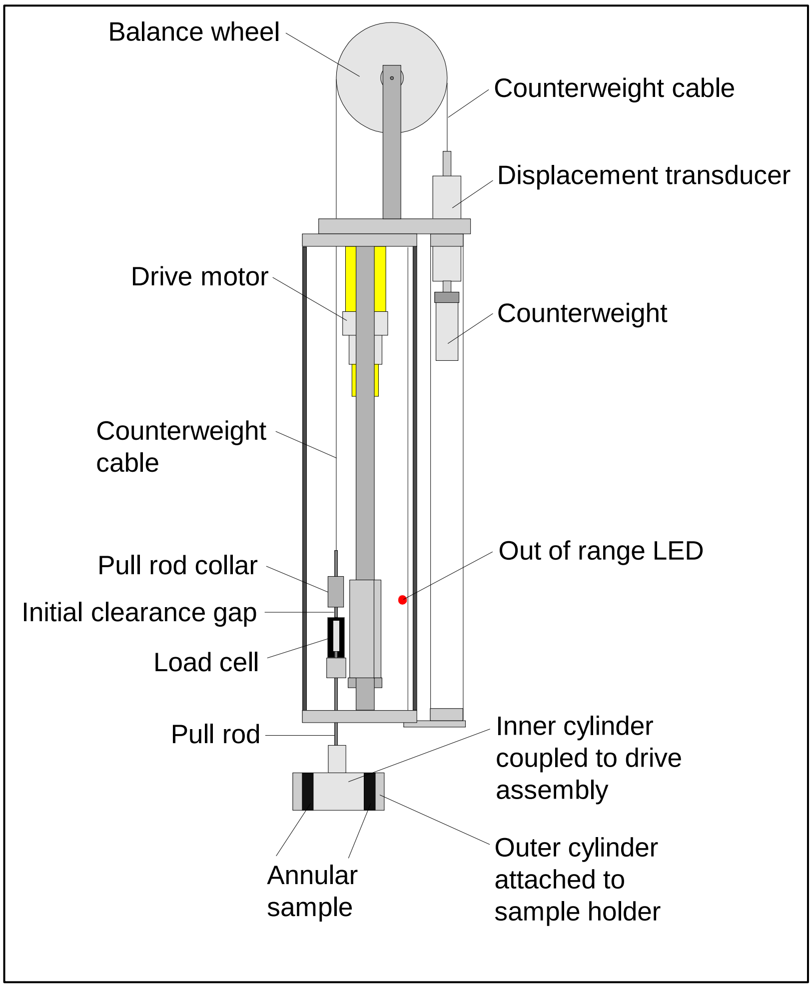


**Figure 2.2: Schematic diagram of moulds A, B and C**

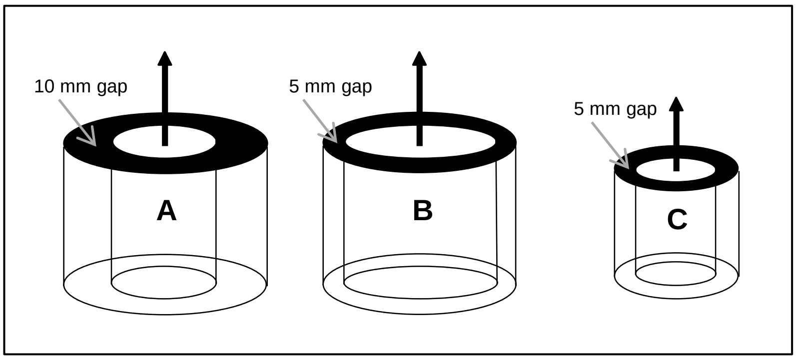


**Table 2.1: Concentric cylinder mould geometry**

| Item | | Unit | Mould A | Mould B | Mould C |
|---|---|---|---|---|---|
| Inner cylinder diameter | $d_1$ | mm | 25.00 ± 0.02 | 35.00 ± 0.02 | 12.00 ± 0.02 |
| Outer cylinder diameter | $d_2$ | mm | 45.00 ± 0.02 | 45.00 ± 0.02 | 22.00 ± 0.02 |
| Height | h | mm | 40.00 ± 0.02 | 40.00 ± 0.02 | 20.00 ± 0.02 |
| Inner cylinder mass | M | g | 54.50 ± 0.05 | 105.50 ± 0.05 | 18.8 ± 0.2 |
| Gap | G | mm | 10 | 5 | 5 |
| Approximate stress factor | K | $(m^2)^{-1}$ | 227.36 | 198.94 | 936.21 |

(f) Forced convection oven – Conforming to the requirements of AGPT/T102.

(g) Pouring containers – 100 mL beakers, or small cans, with a pouring lip (other sizes may be required).

(h) Safety razor blade or other similar device.

(i) Broad bladed spatula.

(j) Freeze spray or silicone grease.

(k) Calliper – Readable to 0.01 mm.

(l) Balance of suitable capacity, accurate to at least 0.01 g.

# 3. Calibration

The operational conditions of the instrument must be periodically checked, as follows:

## 3.1 General

(a) Sample moulds – Regularly check the moulds for damage. Regularly check the mass of the inner cylinders and the dimensions of the inner and outer cylinders. Do not use any mould that has mass or dimensions outside the ranges specified in Table 2.1.

(b) Level – Regularly check the level of the instrument to ensure that the pull rod hangs centrally and clears the hole in the load cell.

(c) Counterweight cable – Regularly check the counterweight cable to ensure there are no obvious kinks (particularly around the balance wheel). If the kinks in the cable cannot be straightened out, then install a replacement cable.

## 3.2 Electronics

The instrument control unit and computer must be switched on at least half an hour before use to allow the electronics to stabilise. The instrument must be operated in a stable temperature environment, as substantial temperature changes can influence the accuracy of the system.

The calibration of force and displacement is automated, with minimal actions required by the operator. The procedures are self-contained, with full instructions on the computer screen via the control software. The calibration routines are selected under ‘Calibration Menu’ in the Windows 3.1 version of the software and the ‘Calibration button’ in the opening menu of the Windows 7 version of the software.

It is recommended that a validation check of the calibration be performed by running a mould A insert alone and noting the variation in peak force and final displacement at least at the beginning of each day of testing.

# 4. Preparation of Samples

## 4.1 General

Bituminous binders can be complex mixtures of a variety of petroleum products. If handled in accordance with the directions of the suppliers, there should be no significant burns risk. However, it is recommended that notices, describing the action to be taken in the event of hot binder burns, should be displayed in the laboratory in the areas where bituminous binders are handled. A suitable warning could be as follows:

**WARNING: HOT BITUMINOUS BINDERS CAN CAUSE SERIOUS BURNS**

Precautions:

(a) Eye protection, such as safety glasses and/or face shields, shall be worn.

(b) Heat-resistant gloves with close-fitting cuffs, and other suitable protective clothing, shall be worn.

(c) There shall be no smoking or the presence of other ignition sources in close proximity.

(d) Bituminous binders heated in the presence of small quantities of water may foam excessively and spatter or overflow the sample containers. Thus samples should always be checked for the presence of water while still cold by examining whether a layer of condensate is evident, either on the surface of the sample or on the underside of the container lid, or if the binder surface exhibits a pitted appearance. In such cases where water is found to be present, drain off as much as possible and dry the sample at room temperature or blow-dry with clean compressed air. Where moisture contamination has been detected or is suspected, the sample needs to be handled with extra care, as described in AGPT/T102.

## 4.2 Sample Preparation

Samples for testing shall be provided in accordance with AGPT/T101 and AGPT/T102.

## 4.3 Pouring Containers

Smaller containers, with a pouring lip to facilitate the pouring of the binder, may be used to fill the sample moulds prior to testing if desired. Small beakers (~100 mL) are recommended for this purpose. For higher consistency binders, a number of small containers may be needed. For more fluid binders, a larger container may be used to fill several moulds, before the material becomes too viscous to pour easily.

Note: The temperatures and times for heating and stirring may need to be varied for certain materials in accordance with recommendations from suppliers.

# 5. Procedures

## 5.1 Preparation of Moulds

The procedure for the preparation of the concentric moulds shall be as follows:

(a) Assemble the mould(s) with the Teflon gasket and baseplate in place. The Teflon gasket may be lightly coated with silicone grease. Use polymer precoated inner cylinder(s) if they are needed to stop the binder sample(s) from partially detaching from the cylinder(s) during testing.

Note: Sample slippage can occur where the sample becomes partially detached from the inner cylinder during testing. This is most likely to occur with samples containing high concentrations of styrene-butadiene-styrene (SBS) polymer in bitumen. The condition can be identified by examining the sample mould after testing. A means of reducing slippage is to deposit a film of SBS polymer on the inner cylinders before casting the sample in the mould. This can be done by painting the appropriate surfaces with a 10% by mass solution of polymer in toluene and then allowing the toluene to evaporate in air overnight in a laboratory fume hood.

(b) Preheat the moulds in the oven to the sample handling temperature (180 °C, unless otherwise specified).

(c) Remove the assembled mould(s) from the oven and place on a horizontal surface (e.g. a laboratory bench).

(d) Take the heated sub-sample and stir thoroughly, but gently, for 30 seconds to assure uniformity of the binder. Avoid trapping air.

(e) Pour the binder into the annular gap of the mould until it is just over-filled, as evidenced by the formation of a slight meniscus. Pour from one point only to avoid trapping pockets of air within the sample. Return the unused sub-sample to the oven to keep hot for topping up later.

(f) Allow the mould(s) to cool in air for 20 minutes. Re-stir the unused sub-sample briefly and top up the mould so that a distinct meniscus forms on top of the binder in the annular gap. On cooling, the binder will contract to just fill the mould.

(g) Cool the mould(s) in air (at 23 ± 3 °C) for a further two hours from the time of addition of the top-up binder.

(h) Remove any excess binder protruding above the mould using a safety razor blade (or other similar device) to create a flat surface. Warming the blade may be helpful to prevent it sticking to the binder.

(i) Clean up the outside surfaces of the mould and the base of the inner cylinder with a clean rag or paper towel dampened with a suitable solvent (e.g. kerosene). The base of the mould (inner cylinder in particular) must be free of binder otherwise it may stick to the sample holder (see Figure 5.1) and interfere with the operation of the test. For the same reason, the centre of the sample holder (i.e. the ‘stop’ for the inner cylinder) should be kept clean. After cleaning, place the mould on a horizontal surface until required for testing.

Note: A sharp peak in the force will occur at the start of an elastometer test if the inner cylinder and centre of the sample holder have not been cleaned appropriately. This peak is due to residual binder being present between the inner cylinder and sample holder which sticks the two components together.

## 5.2 Loading Samples into the Elastometer

The procedure for loading samples into the elastometer shall be as follows:

(a) Maintain the water bath at the required test temperature, within ± 0.1 °C. If testing is required at different temperatures on the same day, it is preferable to start with the lower temperatures first, as only heating is then subsequently required.

(b) Ensure that the water level is to the top of the perforated baffle and is maintained during testing. Any significant change of level will affect the buoyancy of the submersed parts and thus the balance of the system.

(c) Before loading the sample mould into the instrument, ensure that the drive unit is correctly positioned. There should be a minimum clearance gap of 0.5 mm between the load cell and the pull rod collar (see Figure 2.1) after the sample mould is in place. Normally the drive unit is automatically positioned correctly after a test run. If this is not the case, then position it using the up/down switch on the motor controller, move the drive unit up about 1 mm and then down until it automatically stops in the correct starting position, which is indicated by the illumination of the ready light on the motor controller module.

(d) Unscrew the mould from its assembly base, and remove the Teflon gasket by squirting it with the freeze spray and pulling it off briskly. If the gasket was coated with silicone grease during mould assembly, then it may be removed without the spray.

(e) Load the sample into the elastometer. Locate the sample mould in the sample holder, with the flats on the outer cylinder lining up with the holding screws (inner cylinder pin uppermost). Then twist the mould about a quarter turn and tighten the sample mould clamp screws.

(f) Ensure a correct counterweight (per mould type) is used (refer to Figure 2.1).

(g) Lower the pull rod fully over the inner cylinder shaft and tighten the grub screws securely, without using excessive force. Mould C requires a length extension piece between the inner cylinder and the pull rod. Figure 5.1 and Figure 5.2 illustrate the way in which samples should be loaded into the elastometer.

(h) Slowly lower the elastometer into the water bath and position the perforated baffle evenly around the sample holder.

(i) Remove any air bubbles trapped under the sample, after it has been immersed in the water bath for about 30 seconds. This is done by opening the valve on the flushing tube for a short period, which squirts a jet of water under the sample until all trapped air bubbles have been displaced.

(j) Leave the sample for 15 minutes to achieve temperature equilibrium before testing.

**Figure 5.1: Sample arrangement, with details and mounting action**

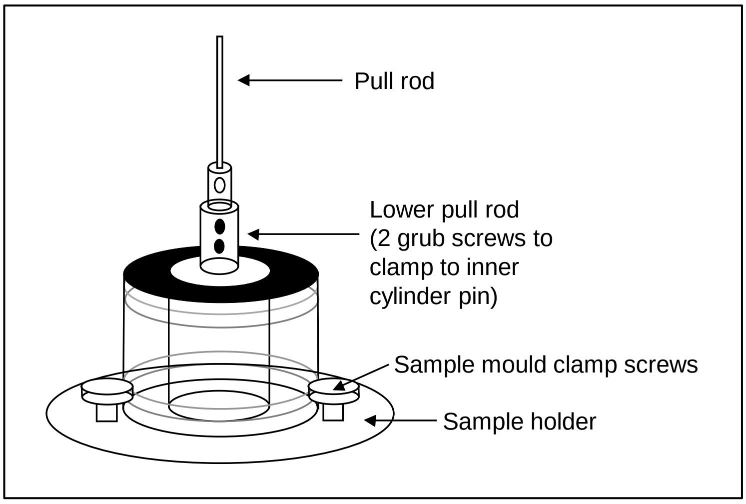
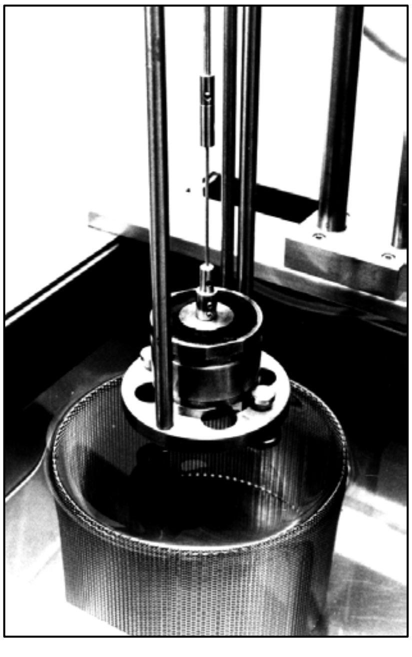


**Figure 5.2: Mould in elastometer**



## 5.3 Elastometer Adjustments

### *5.3.1 For Systems Running under Windows 3.1*

All operating adjustments are made using the computer.

(a) Select ARRB PMB Test System from the Program Manager to bring up the operations main menu.

(b) Select the Elastometer/Run Test function to bring up the elastometer Run Parameters window.

(c) Enter all relevant details of the experiment as requested. The test cannot progress until all required information has been supplied. The following information will be required:

1. Run number, date and time (automatic).
2. Operator.
3. Sample mould. Select A, B or C as required.
4. Temperature.
5. Strain rate (or speed).
6. Strain (or breakpoint).
7. Recovery time (duration of recovery phase).
8. Timer – Select the required time delay before the test starts after pressing START.
9. Mode – Select Recovery. (Relaxation is for future development)
10. Sample description. Two lines of text available.*
11. Comments (optional). Three lines of text available.*

* Do not use ‘enter’ after the second (or third) line, as this will delete first line of text.

Note:

An anomaly in the Windows 3.1 version of the elastometer software in the handling of new file numbers can lead to data losses if a strict run closure protocol is not followed. If the instrument terminates operation because of a fault, or the results of a previous elastometer test are reviewed, the run number counter may not increment to the next logical file number when the next test is performed. This can lead to the over-writing of old data files which results in the loss of previous results. Copying data files to alternative suitably named directories can safeguard old data. Ensuring the program passes through a full closure on completion of each test cycle is strongly recommended. If an old elastometer test result is reviewed, then the run number counter can be reset by reviewing the latest test result that was determined using the elastometer.

For the standard test conditions (strain = 1.0 and strain rate = 0.1 $s^{-1}$), the breakpoint and speed used with mould A (10 mm gap) are 10.0 mm and 1.0 mm/s, respectively. The standard test conditions (strain = 1.0 and strain rate = 0.3 $s^{-1}$) used with mould B (5.0 mm gap) correspond to a breakpoint and speed of 5.0 mm and 1.5 mm/s, respectively. The standard test conditions (strain = 1.0 and strain rate = 0.1 $s^{-1}$) used with mould C (5.0 mm gap) correspond to a breakpoint and speed of 5.0 mm and 0.5 mm/s, respectively.

The normally specified recovery time is 100 seconds (Austroads AGPT/T190).

### *5.3.2 For Systems Running under Windows 7*

All operating adjustments are made using the computer.

(a) Open the ‘Elastometer for Win 7’ shortcut from the desktop.

(b) Select ‘Elastometer Session’ from the main operations window.

(c) Enter all relevant details of the experiment as requested. The test cannot progress until all required information has been supplied. The following information will be required:

1. Run number, date and time (automatic).
2. Operator.
3. Sample description. Two lines of text are available.*
4. Comments (optional). Three lines of text are available.*
5. Sample mould. Select A, B or C as required.
6. Timer – Select the required time delay before the test starts after pressing START.
7. Temperature.
8. Strain rate (or speed).
9. Strain (or breakpoint).
10. Recovery time (duration of recovery phase).
11. Elastometer mode – Select Recovery. (Relaxation is for future development).

* Do not use ‘enter’ after the second (or third) line, as this will delete first line of text.

Note:

For the standard test conditions (strain = 1.0 and strain rate = 0.1 $s^{-1}$), the breakpoint and speed used with mould A (10 mm gap) are 10.0 mm and 1.0 mm/s, respectively. The standard test conditions (strain = 1.0 and strain rate = 0.3 $s^{-1}$) used with mould B (5.0 mm gap) correspond to a breakpoint and speed of 5.0 mm and 1.5 mm/s, respectively. The standard test conditions (strain = 1.0 and strain rate = 0.1 $s^{-1}$) used with mould C (5.0 mm gap) correspond to a breakpoint and speed of 5.0 mm and 0.5 mm/s, respectively.

The normally specified recovery time is 100 seconds (Austroads AGPT/T190).

## 5.4 Testing

The elastometer can be started in two modes, either directly, or via a timer delay function. The delay mode has been provided to allow a 15 minute (900 second) period for temperature equilibration of the sample, after which the test is automatically started (other times are available if required).

(a) Direct mode – Set the timer to 0 minutes in the Run parameters in the Windows 3.1 version of the software or 0 seconds in the Windows 7 version of the software. Leave the sample for 15 minutes to achieve temperature equilibrium, and then press START to begin the test.

(b) Timer mode – Set the timer to 15 minutes in the Run parameters in the Windows 3.1 version of the software or 900 seconds in the Windows 7 version of the software. Press START as soon as the run parameters have been entered and the sample has been lowered into the bath. The timer will then count down for 15 minutes and start the test automatically after this period. The test sequence and data acquisition will progress automatically. While the test is running, progress is displayed on the screen as time elapses during each of the phases.

# 6. Results

Both versions of the elastometer software will provide a summary of the experimental conditions used during each test as well as values of consistency (in Pa.s), stiffness (in Pa) and elastic recovery (in %). If stiffness test results need to be reported then the results displayed by the elastometer software should be divided by 1000 so that they are expressed in kPa.

The Windows 7 version of the elastometer software also displays a value of consistency 6% (in Pa.s) for the binder that was tested. If the Windows 3.1 version of the software is used, consistency 6% test results can be calculated using the method described in Appendix A.

# 7. Information to be Reported

The information shown in Table 7.1 shall be reported for consistency and stiffness measurements, respectively.

**Table 7.1: Parameters to be reported in consistency and stiffness tests**

| Consistency tests | Stiffness tests |
|---|---|
| Consistency in Pa.s to the nearest integer | Stiffness in kPa to the nearest integer |
| Consistency 6% in Pa.s to the nearest integer | – |
| Test temperature in °C to the nearest 0.1 °C | Test temperature in °C to the nearest 0.1 °C |
| Strain rate in $s^{-1}$ to two decimal places | Strain rate in $s^{-1}$ to two decimal places |
| Strain to two decimal places | Strain to two decimal places |
| Elastic recovery (in %) to the nearest integer | Elastic recovery (in %) to the nearest integer |
| Elastic recovery time (s) to the nearest integer | Elastic recovery time (s) to the nearest integer |
| Test mould (A, B or C) | Test mould (A, B or C) |

# 8. Precision

A test result should be considered valid if the measured consistency is greater than 1000 Pa.s. If the value of consistency falls within the range of 500 to 1000 Pa.s, then the consistency result will still be acceptable. However, if the consistency result is below 1000 Pa.s, then the associated elastic recovery result will become unreliable. Consistency results less than 500 Pa.s can be acceptable, however, the associated elastic recovery results should be discarded.

The upper limits of testing are determined by the maximum force that can be measured by the elastometer load cell (200 N) and the geometry of the sample assembly used. Table 8.1 gives the maximum consistency and stiffness results that can be determined using each of the three elastometer moulds when standard test conditions are used. It is unlikely that samples will exceed the maximum limits of consistency that can be measured by the elastometer. Some samples, however, can show stiffness at 15 °C results with mould C that are higher than the limits shown in the table.

The elastometer software will stop a measurement during the loading phase at the point at which the force measured from a sample exceeds 200 N (in order to protect the load cell). If this occurs, then the ‘actual strain’ and ‘actual breakpoint’ recorded by the elastometer software will be significantly less than those that were entered during the elastometer adjustments (Section 0). If a sample exceeds the force measurement limit of the elastometer during a test it is recommended that the stiffness result be recorded as a result greater than the value shown in Table 8.1 (e.g. > 187 kPa). The elastic recovery result obtained during the test should be disregarded as the recovery phase of the measurement did not begin at the set strain value.

**Table 8.1: Maximum consistency and stiffness results that can be measured under standard test conditions**

| Mould | A | B | C |
|---|---|---|---|
| Strain rate ($s^{-1}$) | 0.1 | 0.3 | 0.1 |
| Strain | 1.0 | 1.0 | 1.0 |
| Maximum consistency (Pa.s) | 454 728 | 132 629 | 1 872 411 |
| Maximum stiffness (kPa) | 46 | 40 | 187 |

# Appendix A Data Analysis Methods

This appendix describes the method by which the values of actual strain rate, strain, stress, peak stress, consistency, stiffness, consistency 6%, and elastic recovery are calculated using the Windows 7 version of the elastometer software. These details have been included for information and include information about how values of consistency 6% can be calculated when the Windows 3.1 version of the software is used.

Once an elastometer test has been completed, both versions of the software generate three text files. These include a header file (*.hed), a loading phase file (*.lod) and a recovery phase file (*.rec). The number associated with each file corresponds to the elastometer run number. The header file contains a summary of the test conditions and final test results obtained during a test. The loading phase file contains all the values of time, force and displacement recorded during the loading phase of a test. The recovery phase file contains all the values of time, displacement and elastic recovery recorded during the recovery phase of a test.

## A.1 Actual Strain Rate

The actual strain rate used during a test depends on the sample film thickness (mould gap) and the speed the sample moves during the loading phase. The actual strain rate is calculated by the elastometer software using Equation A1:

$$\text{Actual strain rate}\left(s^{-1}\right) = S/G \qquad \text{A1}$$

where

S = speed of the inner cylinder (mm/s)

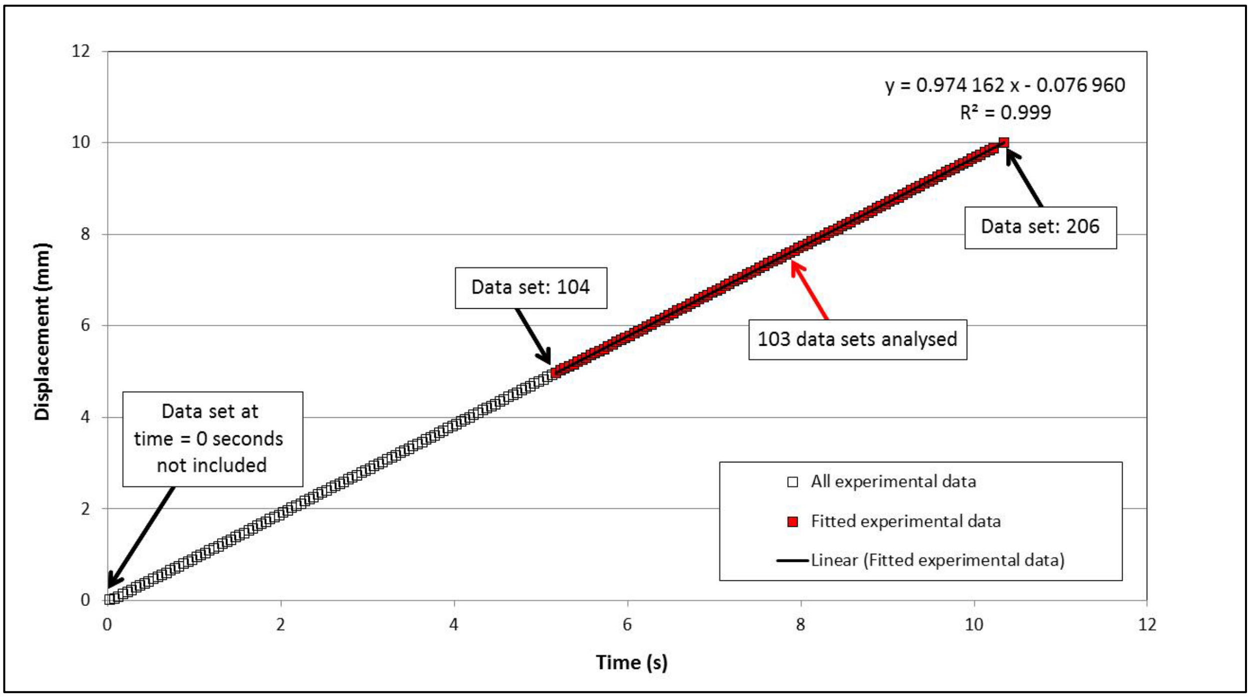
G = annular gap in the mould (mm)

The speed of the inner cylinder during the loading phase is calculated by the elastometer software by determining the gradient of a linear fit on the last half of the recorded time-displacement data. An example of this type of fit is shown in Figure A1. The data shown in Figure A1, Figure A2 and Figure A3 were all derived from a single elastometer experiment using mould A.

The program initially determines the specific data points to be fitted by first removing the set of time-displacement data entries obtained at a time of 0 seconds. The elastometer software discards this set of data entries as the software records all parameters as zero at this point in the test. After the first set of data entries has been removed, the elastometer software then counts the number of time-displacement data entries remaining that were measured during the loading phase (N, e.g. 206 data entries in the example shown in Figure A1). After the elastometer software has determined a value of N, it then divides this number by two (N/2, which corresponds to 103 data entries in the example shown in the figure) and rounds this number down to the nearest whole number if required. The program then performs a linear fit on the last N/2 sets of time-displacement data that were obtained during the loading phase (after rounding the value of N/2 down to the nearest whole number).

The speed of the inner cylinder is then taken by the program to be the gradient of the linear fit after it has been rounded to six decimal places (0.974 162 mm/s in the example below). The actual strain rate is then calculated to seven decimal places using Equation A1. For the test conducted using mould A which is shown in Figure A1, the elastometer software yielded an actual strain rate result of 0.097 4162 $s^{-1}$ (i.e. (0.974 162 mm/s)/(10 mm)).

**Figure A1: Example of the fitting analysis used by the elastometer software to calculate the speed of the inner cylinder**



Note: The original data (which is also contained in the loading phase file (*.lod)) contained 207 sets of data entries, including the set of data entries obtained at a time of 0 seconds where the elastometer software records all test parameters as zero. After the data set at a time of 0 seconds was removed, 206 sets of data entries remained to be analysed by the elastometer software.

## A.2 Strain

The strain experienced by a sample depends on its displacement and film thickness (mould gap). Displacement values are converted into strain values by the elastometer software using Equation A2:

$$\text{Strain} = B/G \qquad \text{A2}$$

where

$B$ = sample displacement (mm)

$G$ = annular gap in the mould (mm)

Actual strain results reported by the elastometer are calculated using the highest displacement reading obtained during the loading phase and Equation A2.

## A.3 Stress

The stress experienced by a sample depends on the force measured and a stress factor which depends on the type of mould used. The stress factor is the reciprocal of the mean area of the annular sample being sheared. The elastometer software converts force values to stress values using Equation A3:

$$\text{Stress (Pa)} = K \times F \qquad \text{A3}$$

where

$K$ = mould stress factor $(m^2)^{-1}$

$F$ = measured force (N)

The mould stress factor is calculated using Equation A4:

$$K = \frac{1}{0.5\,\pi\,h\,(d_1 + d_2)} \qquad \text{A4}$$

where

$h$ = height of sample mould (m)

$d_1$ = inner cylinder diameter (m)

$d_2$ = outer cylinder diameter (m)

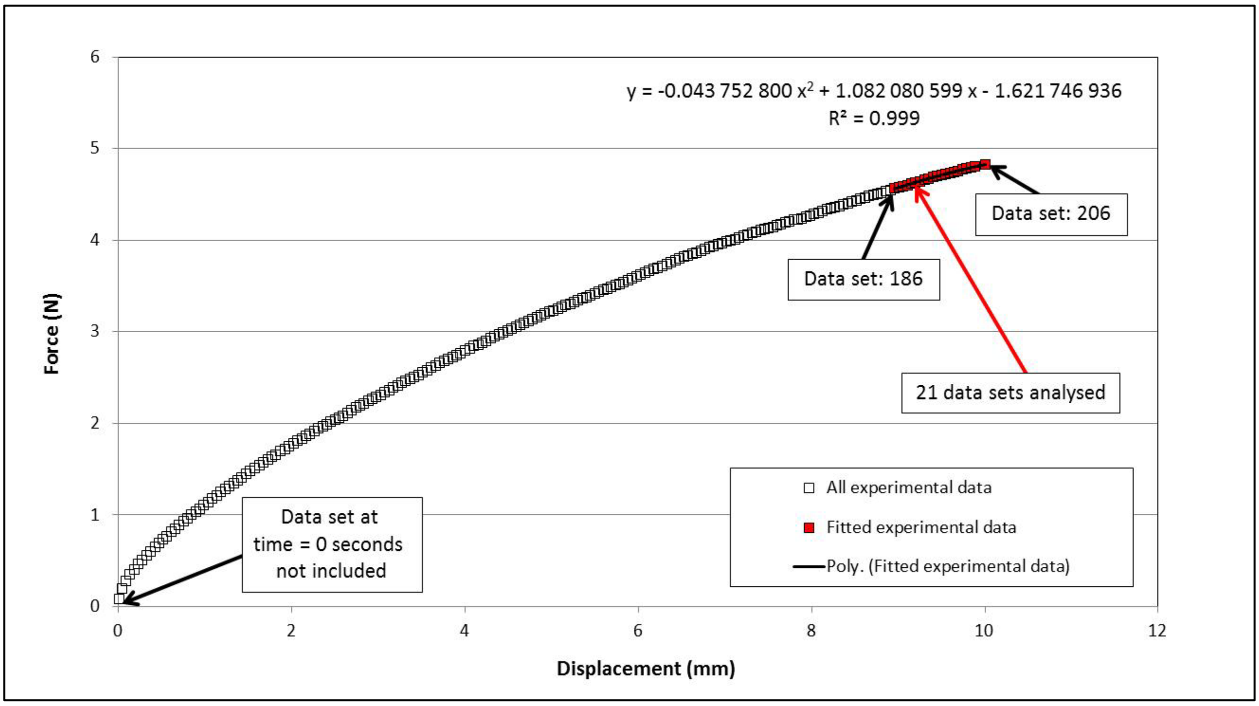
Values of h, $d_1$ and $d_2$, as well as approximate mould stress factor values, are listed for each of the three elastometer moulds in Table 2.1. The elastometer software uses Equation A4 to calculate mould stress factors and does not round the result. If any elastometer results are calculated using the data contained in a loading phase file (*.lod) then Equation A4 should be used to calculate mould stress factors, and the results should not be rounded. If the approximate stress factors shown in Table 2.1 are used in the calculations, then the results obtained from analysing the data in a loading phase file will be slightly different from those calculated by the elastometer software.

## A.4 Peak Stress

The peak stress is used to calculate the consistency or stiffness of the binder tested. It is defined as the force attained at the strain or breakpoint which was entered during the elastometer adjustments (Section 0), divided by the mean area of the annular sample being sheared. In terms of standard test conditions, it corresponds to the stress observed from a sample at a strain of 1.0.

The elastometer software initially calculates the peak force at the breakpoint by fitting the last 10% of the displacement-force data that was recorded during the loading phase to a quadratic function (i.e. an equation of the form, $y = ax^2 + bx + c$). The breakpoint that was set prior to the test is then substituted into the fitted equation so that the peak force from the binder can be calculated. This fitting process is used to remove noise from the raw elastometer data. An example of the type of fit used to calculate the peak force of a binder is shown in Figure A2.

**Figure A2: Example of the fitting analysis used by the elastometer software to calculate the peak force at the breakpoint**



The program initially determines the specific data points to be fitted by first removing the set of displacement-force data entries obtained at a time of 0 seconds. After the first set of data entries has been removed, the elastometer software then counts the number of displacement-force data entries remaining that were measured during the loading phase (N, e.g. 206 data entries in the example shown in Figure A2). It then divides this number by 10 (N/10, which corresponds to 20.6 data entries in the example shown in the figure) and rounds this value to the nearest whole number (e.g. 21). The program then performs a quadratic fit on the last N/10 sets of displacement-force data obtained during the loading phase (after rounding the value of N/10 to the nearest whole number).

The elastometer program determines the fitted coefficients of the quadratic fit (i.e. a, b and c) to a large number of decimal places. If elastometer results are calculated using the data contained in a loading phase file (*.lod) it is recommended that the coefficients of the quadratic fit be determined to the order of 10 significant figures (as in the case of the fit shown in Figure A2) so that the results obtained from the analysis of the loading phase file agree with those calculated using the elastometer software. In the case of the example shown in Figure A2 , substitution of the standard mould A breakpoint of 10 mm into the fitted equation yielded a peak force of 4.823 799 N.

Once the elastometer software has calculated the peak force obtained for a binder, it then uses Equation A3 to calculate the peak stress. For the example shown in Figure A2 , the peak stress was determined to be 1096.755 Pa.

## A.5 Consistency and Stiffness

Once the elastometer software has calculated the peak stress obtained for a binder it then calculates values of consistency and stiffness. The consistency of a binder is determined using Equation A5:

$$\text{Consistency (Pa.s)} = \frac{\text{Peak stress (Pa)}}{\text{Actual strain rate (s}^{-1}\text{)}} \qquad \text{A5}$$

where

peak stress is as calculated in Appendix A.4

actual strain rate is as calculated in Appendix A.1.

The stiffness of a binder is calculated using Equation A6:

$$\text{Stiffness (Pa)} = \frac{\text{Peak stress (Pa)}}{\text{Strain}} \qquad \text{A6}$$

where

peak stress is as calculated in Appendix A.4

strain is the strain value that was entered during the elastometer adjustments (Section 0).

For the example binder shown in Figure A1 and Figure A2, consistency and stiffness values of 11 258 Pa.s and 1069 Pa, respectively, were determined by the elastometer software.

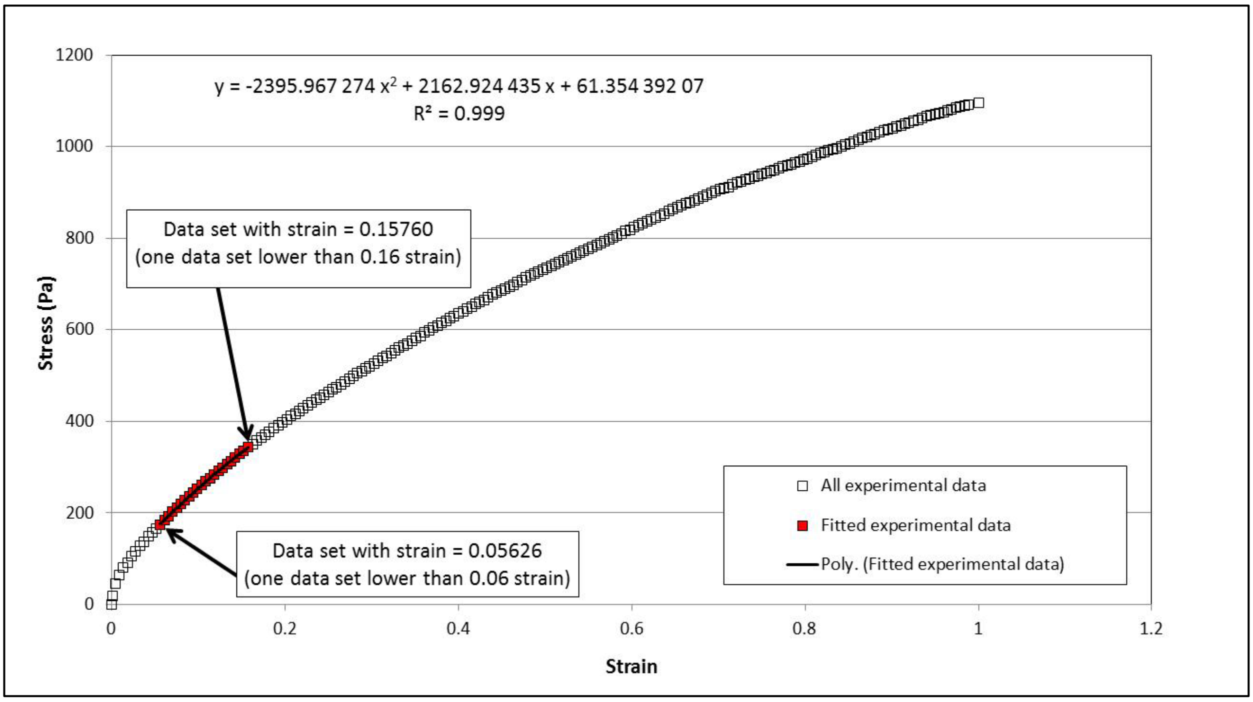
## A.6 Consistency 6%

The elastometer software calculates consistency 6% results by initially converting the displacement and force data obtained during the loading phase to values of strain and stress using Equation A2 and Equation A3, respectively. Once the data has been converted, it then selects the strain-stress data in the range that has stress values between one data set lower than 0.06 strain and one data set lower than 0.16 strain. The selected data is then fitted to a quadratic function. This fitting process is used to remove noise from the raw elastometer data. An example of the type of fit used to calculate the stress recorded from a binder at 0.06 strain is shown in Figure A3 . The data shown in Figure A3 was obtained during the same elastometer run as the other two figures shown previously in this appendix.

As in the case of the determination of peak stress (Appendix A.4), the elastometer software determines the fitted coefficients of the quadratic fit to a large number of decimal places. If elastometer results are calculated using the data contained in the loading phase file (*.lod) it is recommended that the coefficients of the quadratic fit be determined to the order of 10 significant figures (as in the case of the fit shown in Figure A3).

In the case of the example shown in Figure A3, substitution of a strain of 0.06 into the fitted equation yielded a stress value of 182.5044 Pa.

**Figure A3: Example of the fitting analysis used by the elastometer software to calculate the stress at 0.06 strain**



Once the elastometer software has calculated the stress at 0.06 strain it then determines the consistency 6% result for the binder using Equation A7:

$$\text{Consistency 6\% (Pa.s)} = \frac{\text{Stress at 0.06 strain (Pa)}}{\text{Actual strain rate (s}^{-1}\text{)}} \qquad \text{A7}$$

where

stress at 0.06 strain is calculated using the method described above

actual strain rate is as calculated in Appendix A.1.

For the example binder shown in Figure A1 and Figure A3, a consistency 6% result of 1873 Pa.s was determined by the elastometer software.

## A.7 Elastic Recovery

Elastic recovery is a measure of the elasticity of a binder under specific conditions of testing. It is defined as the recovered strain, as a percentage of the original strain attained at the end of the loading phase. As the strain on a sample is related to its displacement by a constant factor (Equation A2), elastic recovery can be also considered to be the recovered displacement of a sample, as a percentage of the original displacement attained at the end of the loading phase. The elastometer software calculates elastic recovery values for each set of time-displacement values that are obtained during the recovery phase. Elastic recovery results are calculated from displacement values using Equation A8:

$$\text{Elastic recovery (\%)} = \frac{100\,(d_0 - d)}{d_0} \tag{A8}$$

where

$d_0$ = displacement recorded at the end of the loading phase (mm)

$d$ = displacement recorded after a specific time during the recovery phase (mm)

## A.8 Calculation of Consistency 6% using Microsoft Excel

The points listed below can be used to determine consistency 6% results for binders using the loading phase file (*.lod) generated by the elastometer software and Microsoft Excel. These points are intended to replicate the means by which the Windows 7 version of the elastometer software calculates consistency 6% results.

1. Import the text data in the loading phase data file into Excel after selecting space delimited formatting.
2. Remove the initial data set from the imported data where the results for time, force and displacement are all zero.
3. Count the number of data sets remaining (N) and divide this number by two. Round this number down to the nearest whole number if required (x).
4. Perform a linear fit on the last x sets of time and displacement data and calculate the gradient of the fit to six decimal places. This gradient corresponds to the speed of the inner cylinder in mm/s. Calculate the actual strain rate used during the test (to seven decimal places) using Equation A1.
5. Calculate the mould stress factor using Equation A4 using the Excel function PI() for $\pi$. Note that the units used in Equation A4 are m not mm.
6. Convert the values of displacement and force in the Excel file into strain and stress results using Equation A2 and Equation A3. Use the mould stress factor determined in step 5 above in Equation A3.
7. Select the strain-stress data which covers strain values that are between one data point lower than 0.06 strain and one data point lower than 0.16 strain. Perform a quadratic fit on the selected data and ensure that the fitted coefficients contain at least 10 significant figures. Calculate the stress at 0.06 strain by substituting 0.06 into the fitted equation.
8. Calculate the consistency 6% result using Equation A7.

# Amendment Record

| Amendment no. | Clauses amended | Action | Date |
|---|---|---|---|
| 1 | Commentary page<br>Header and footer<br>Applied revised test method number<br>Applied new styles | New<br>Format<br>Format<br>Format | June 2005 |
| 2 | Applied new test method numbers<br>Moved notes to end of method | Substitution<br>Format | March 2006 |
| 3 | Corrected references within test method | Substitution | June 2006 |
| 4 | Removed redundant notes | Removed | October 2008 |
| 5 | Addition of underlying viscosity terms<br>Safety precaution statement (Item 4.1) | New<br>Substitution | August 2010 |
| 6 | Table of contents added<br>Text styles amended and new header and footer added.<br>Manual elastometer-related statements removed<br>Safety statements updated<br>Underlying viscosity term replaced with consistency 6%<br>Updated test method to include the use of the Windows 7 version of the elastometer software<br>Original notes section removed and individual notes placed in appropriate sections of the text<br>Added appendix to describe the data analysis methods used by the elastometer software<br>Removed old data analysis appendix and elastometer operation summary appendix | New<br>Format<br>Removed<br>Substitution<br>Substitution<br>New<br>Format<br>New<br>Removed | February 2014 |

**Key**

| | |
|---|---|
| Format | Change in format |
| Substitution | Old clause removed and replaced with new clause |
| New | Insertion of new clause |
| Removed | Old clauses removed |