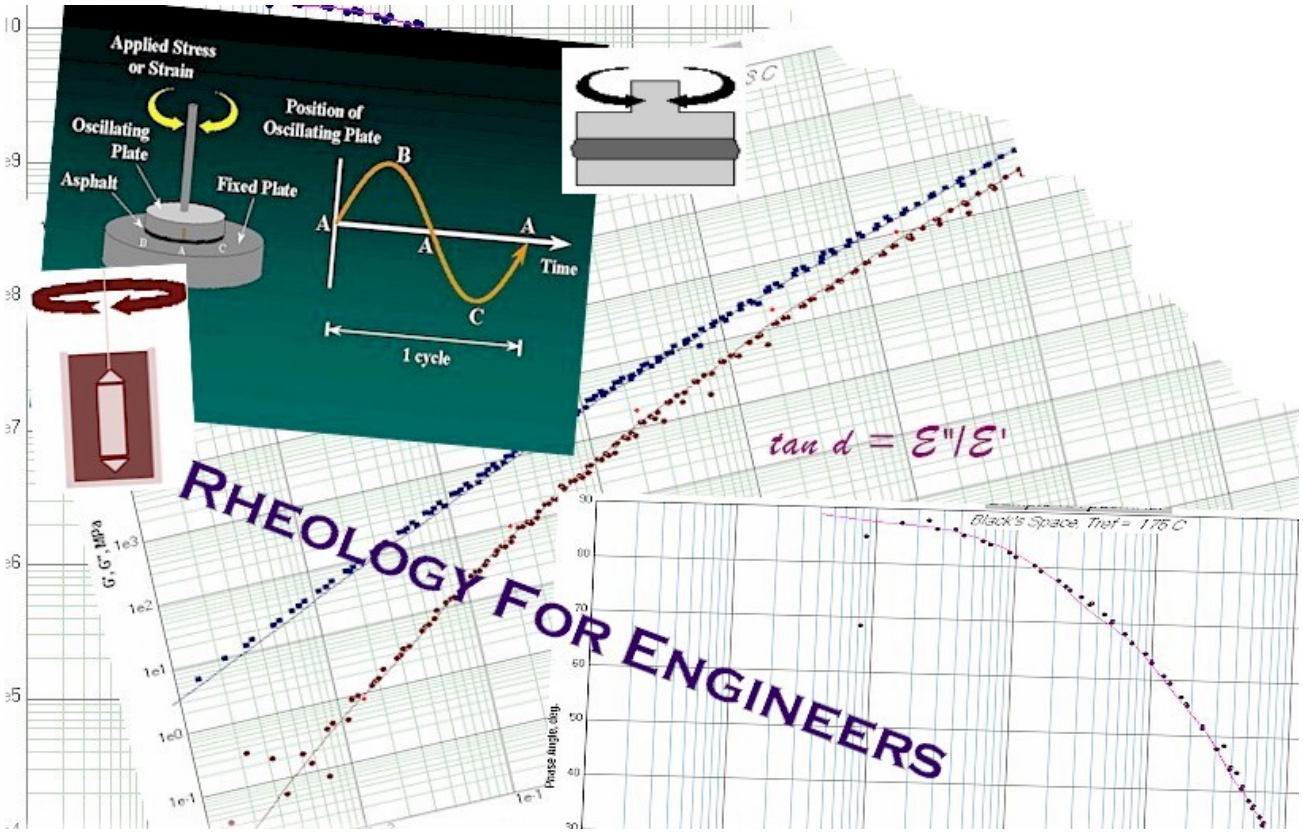
Rheology Analysis Software Users Manual

RHEA™



ABATECH, INC.

PO Box 356

Blooming Glen, PA 18901

TEL: (215) 258-3640

FAX: (772) 679-2464

EMAIL: INFO@ABATECH.COM

-Important Notice-

You have been provided with a software security dongle, which enables you to use the RHEA™ software on your computer. The dongle should be considered as a very valuable device that is not easily replaced. This ensures copy protection of the software and restricts use to authorized users. It protects our software against software theft.

A high replacement fee is charged if this device is lost and/or stolen. We advise that you insure the dongle for the value of the software.

Please make sure that you connect the dongle to your parallel port before running the software.

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Introduction

Thank you for obtaining a copy of the **RHEA™** software. The **RHEA™** software is a rapid user-friendly method to analyze data from frequency sweep, relaxation or creep experiments to determine a wide range of visco-elastic properties that are used in specifications.

RHEA™ has been specifically developed for engineers working in rheology needing a rapid analysis procedure. Master-curves of stiffness or compliance information in either time or frequency domain are generated from dynamic or creep data. For example, in the asphalt industry, the Superpave specification and mixture design process involves the collection of dynamic data for both binder and mixture specifications. In the plastics industry, dynamic mechanical data is used for understanding the complex behavior of polymers over a wide range of frequencies/times. The **RHEA™** software allows users to rapidly inspect the quality of data and to develop the interrelationships with ease.

RHEA™ converts dynamic mechanical data (G', G" vs. ω) from the frequency domain to the time domain, G(t) and J(t) and vice-versa.

FUNCTIONALITY INCLUDES THE FOLLOWING

OSCILLATION EXPERIMENTS

G', G", G*, δ ⟷ G(t) ⟷ J(t)

TIME DOMAIN EXPERIMENTS

Stress Relaxation/Creep Experiments

G(t) ⟷ J(t) ⟷ G', G", G*, δ

Creep Compliance - Indirect Tension etc.

D(t) ⟷ E(t) ⟷ E', E", E*, δ

Creep Compliance experiment - expressed as apparent stiffness (Bending Beam Rheometer)

S(t) ⟷ D(t) ⟷ E', E", E*, δ

The shifted master curves are fitted using a modified non-linear Marquadt-Levenburg least squares optimization. This is followed by a numerical analysis calculating the discrete relaxation and retardation spectra (Baumgaertel and Winter, 1989). The software numerically optimizes the number of

relaxation/retardation modes used in the analysis. A maximum of 32 relaxation modes can be calculated for the data sets.

This program has been developed as a general tool for performing rheological analysis of a wide variety of materials that behave according to linear visco-elastic theory.

This manual provides a functional explanation of the programs working and does not explain the background research. Reference sources are given for the technical papers, which this software is based upon.

Agreement

The software is sold subject to the stipulations as indicated below.

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Setup

The setup operation for **RHEA™** makes use of a setup executable file. In addition, a hardware driver is required for the software protection device (dongle/hardware key).

Installing the Software

The **RHEA™** software will normally be downloaded from Abatech's web site as a ZIP file (Internet site http://www.abatech.com/RheaFile.htm). The user should unzip the files to a temporary directory for install purposes. The user then runs ***setup.exe*** located in the temporary directory. The setup program then asks a few simple questions relating to the location on the computer that you wish to install the files to. **RHEA™** must be installed on a local drive rather than on a network drive.

Note: Should the user wish to remove the program at a later date the user is strongly advised to use the Add/Remove Programs utility located in the Control Panel.

Abatech updates the software by providing downloadable files on its web site - please ensure that you have checked the web site for the most up-to-date version of the software. Updates are provided as a patch file that should be unzipped to a temporary location. A readme.txt file will contain specific instructions to complete the update.

Software Security

The **RHEA™** software is copy protected using SafeNet protection systems with the use of a dongle/hardware key. The dongle must be fixed to the parallel printer port of the machine before the software is started and must remain in place during software use. If you have downloaded this manual and software from our web location you can request the dongle from the technical support team when placing your order for the software.

Windows NT/2000 Users

The software has been prepared to operate on Windows 95, Windows 98, Windows NT, XP and Windows 2000, Vista. However, users with Windows NT, Windows 2000, XP and Vista will require a special file not located on the install disk to avoid receiving an "Error 12" message.

This file "**NTDongleFix.zip**" provides this driver for older versions of Windows whereas "**SSD5411-32bit.zip**" provides a more up to date driver for the newer operating systems. These files may be downloaded from http://www.abatech.com/RheaFile.htm or can be obtained from our technical support

team or from the SafeNet web site. Instructions are provided with the zip files for installation of this driver. If successfully installed, 'Error 12' message will not be displayed. The same setup program can be used to remove the drivers if desired.

Analysis in RHEA

Shifting

The analysis in RHEA makes use of shifting procedures defined by Gordon and Shaw (1994) shifting method. This method consists of steps as follows:

- Determine an initial estimate of the shift using WLF parameters and standard constants
- Refine the fit by using a pairwise shifting technique and straight lines representing each data set
- Further refine the fit using pairwise shifting with a polynomial representing the data being shifted
- The order of the polynomial is an empirical function of the number of data points and the decades of time / frequency covered by the isotherm pair
- This gives shift factors for each successive pair, which are summed from zero at the lowest temperature to obtain a distribution of shifts with temperature above the lowest
- The shift at T_{ref} is interpolated and subtracted from every temperature's shift factor, causing T_{ref} to become the origin of the shift factors

An example of the shift factor development according to this method is shown in Figure 1.

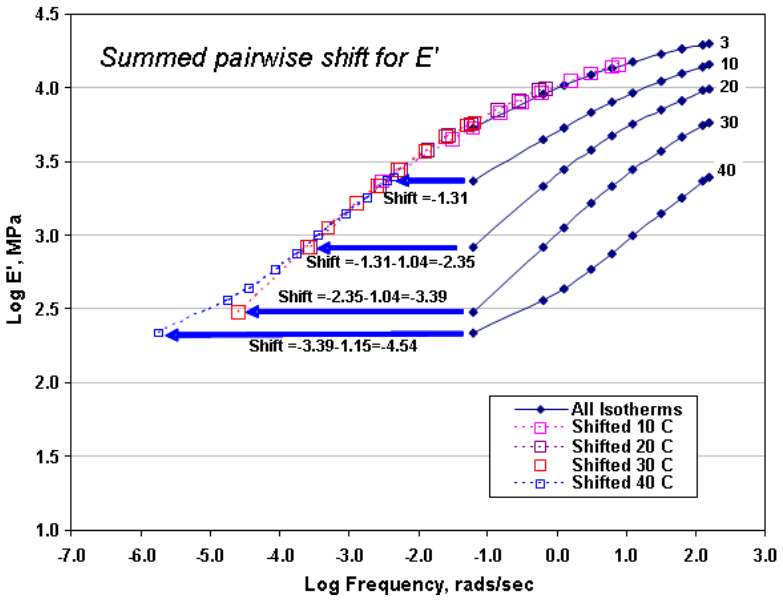

Figure 1: Example of pairwise shift for E' data for dynamic modulus data

After 1st estimate of the shift is made the polynomial expression is optimized using nonlinear techniques. The shift factors are developed by considering the pairwise shift starting from coldest temperature isotherm. For data consisting of loss and storage modulus the shifting is done for both components of modulus and then averaged to produce the final shift. When only a single component is available (i.e. G*, D(t), S(t), etc.) then the shift is only performed one time.

The goodness of the shift produced depends upon the data quality obtained, in particular 1) the number and spacing of data points in each isotherm of data, and 2) the quality of the data with respect to the phase angle collection.

The number and spacing of data points within each isotherm is recommended to be a minimum of 4 to 5 equally spaced points on a logarithmic scale and a maximum of 10 points. This type of sampling scheme ensures that the polynomial fitted to the data in the shifting process is weighted appropriately. If data sets contain large gaps then this may result in a shifting error.

Phase angle data is the most problematic of rheological measurements since calibration standards (Velanker and Giles, 2007). The phase angle measurement relies on good measurements and can be effected by compliance and many other issues. In particular, we have noted that in asphalt mixture work that the phase angle measured is often substandard. Consequently, the software provides an alternate method of shifting for materials collected in dynamic testing in that data can be exported to complex modulus alone, the data file re-read and data shifted using a single shift of complex modulus. Various model parameters are then computed on the shifted modulus values.

Models

Prony Series and Functional Forms

After the data has been shifted various model fits are attempted and applied. These included relaxation/retardation spectra (often referenced as Prony series) and functional forms such as the Christensen-Anderson model (1992) (applied to visco-elastic liquid formulation for asphalt binder and other materials) and the standard and generalized logistic functions (applied to visco-elastic solid formulation for mixtures and other materials) (Verhulst, 1838; Richards, 1959). The Christensen-Anderson model is applied to asphalt binders (bitumen) that generally contain no modification although it has also been applied with success to filled materials. Filled asphalt materials are generally better characterized by visco-elastic solid models and in this can the Verhulst of Richards models are fitted. The Verhulst model has been implemented in pavement design systems and has a long history of usage for asphalt materials referred to as the Witczak model. The user has some choices over the model fitting in that the user can

specify an analysis assuming a visco-elastic solid model or liquid model. Generally, RHEA will determine which fitting method is better for the data set. It should be noted that most data sets can be analyzed as a visco-elastic liquid whereas fewer data sets generally can be forced to follow solid models unless the data shows a solid type asymptote at both end of the master curve.

The discrete spectrum fit uses the method developed by Baumgaertel and Winter (1989) for fitting visco-elastic solid or liquid retardation and relaxation models. The algorithm for fitting the discrete spectrum to the data set requires a given number of points per decade – typically 4 to 5. Consequently in order to generate a well condition discrete spectra calculation the data is smoothed and data points are determined which provide input into the DS calculation. If excessive data points exist – these are the reduced whereas if insufficient data exists extra points are interpolated to allow the calculation to take place. This is termed "smoothed interpolated MC" and is shown in one of the listings.

MEPDG Mastercurve

An alternate option is provided in RHEA which has been developed specifically for the hot-mix asphalt industry – which is the analysis of parameters associated with Mechanistic Empirical Pavement Design Guide. The master curve is of the Verhulst format with the exception that an E* function is provided as a function of time using an approximate empirical relationship adopted in that method. The shift factor is expressed in a polynomial form with this model.

RHEA™ File System

Automatic File Recognition

The RHEA™ software file reader can automatically read and view different data files. The files must be ASCII data files and currently we have tested the software with data collected on the following:

- Anton Paar
- ATS Rheosystems
- Bohlin (DSR) (now Malvern)
- Cannon (BBR)
- Cox and Son (SST)
- Interlaken (SST)
- Malvern (DSR)
- Rheometrics (DSR)
- TA Instruments (DSR)
- and others

The data file format used by the software follows the conventions proposed by Gordon and Shaw (1994) (and further developed within this software) and in practice any rheological data can be handled by the **RHEA™** software. In the current version of the software five file readers are provided - 1) Bohlin, 2) Interlaken, 3) Interlaken (SST), 4) TA Instruments DSR (Format specific) and Cox and Son (SST). In addition, the use may make a data file using any suitable ASCII text editor. File import options with these data files are discussed in Appendix A.

Run File Data format

The ***.ttd** run file is an ASCII text file that can be developed with any editor program. The format of the data file is based the formats proposed by Gordon and Shaw (1994). This format has been extended to allow different experimental conditions to be used and different test types. The format of the file is indicated below.

Format of data file.

Line 1 Description. Any text, on 1 line.

Line 2. Thirteen items as follows:

1	N if natural data or L if log10 data
2	ni = Number of isotherms
3	Tref = Reference temperature °C.
4	Glassy temperature °C
5	Apply density correction: Use 1
6	Expansion coefficients available: Use 1
7	Expansion coefficient below glassy temperature.
8	Expansion coefficient above glassy temperature.
9	Density at 25°C
10	0 = Binder, 1 = Mix
11	H for Hz or R for rad/sec if frequency domain. S = seconds if time domain.
12	G = shear, E = tension or bending, J or D if compliance rather than stiffness, S for apparent stiffness (1/Compliance).
13	Units - eg Pa, kPa, MPa, psi etc.
14	F to enforce analysis as (F)luid; R - let (R)hea decide
15	Wx Tolerance (decades) for "Wild" shift
16	Yx Specify a Glass(y) Modulus

Line 3. Isotherm commences; 2 items as follows:

1	Temperature of isotherm, ascending.
2	nt = Number of times / frequencies.
3	0 = rejected, 1 = selected.

Lines 4 to (3+nt). nt lines, isotherm data points, 3 items / line, as follows

1	Time or Frequency, ascending.
2	Modulus or Compliance if time domain. Storage modulus if frequency domain.
3	1 (Transient) Loss modulus (Dynamic)
4	0 = point rejected, 1 = point selected

For each isotherm, repeat, as from line 3.

Notes:

1) Isotherms must be in ascending order of temperature.
2) Time or Frequency must be in ascending order within Isotherms.
3) If Indirect Tensile Test (IDT) data is input, Tref must be Temperature of coldest isotherm (because a power fit is used for compliance data). Also, in the case of IDT data, the number of data points must be the same in each isotherm.
4) G* can be entered alone with a calculation of phase angle.
5) Does not allow Phase Angle to be input at present, and Shifting cannot be performed on basis of Phase Angle, at present.
6) maximum of 24 isotherms allowed - or - 300 data points.

The example below is a listing from a typical data file – seven isotherms of data.

```
Area 1 - RTFOT residue
L 7  25 -20 1 1 .0002 .00017 1.02 0 H G Pa
5.000 20 1
 -9.9986973e-01  7.0286119e+00  7.0182427e+00 1
 -8.9469424e-01  7.0815633e+00  7.0601688e+00 1
 -7.8933376e-01  7.1400050e+00  7.1066328e+00 1
 -6.8394574e-01  7.1927068e+00  7.1480162e+00 1
 -5.7864290e-01  7.2454386e+00  7.1922328e+00 1
 -4.7324731e-01  7.2960726e+00  7.2341375e+00 1
 -3.6797823e-01  7.3491804e+00  7.2682971e+00 1
 -2.6244957e-01  7.3955535e+00  7.3053944e+00 1
 -1.5735332e-01  7.4471580e+00  7.3458049e+00 1
 -5.1797385e-02  7.4925369e+00  7.3841921e+00 1
  5.3884790e-02  7.5378946e+00  7.4144218e+00 1
  1.5905560e-01  7.5826655e+00  7.4473131e+00 1
```

```
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  3.6992055e-01  7.6704871e+00  7.5157679e+00 1
  4.7712125e-01  7.7093209e+00  7.5473685e+00 1
  5.7949778e-01  7.7494735e+00  7.5754534e+00 1
  6.8472870e-01  7.7878004e+00  7.6045176e+00 1
  7.9588002e-01  7.8288467e+00  7.6342555e+00 1
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  5.3884790e-02  2.6035016e+00  3.0506890e+00 1
  1.5905560e-01  2.6872524e+00  3.1289805e+00 1
  2.6493582e-01  2.7725051e+00  3.2034137e+00 1
  3.6992055e-01  2.8477454e+00  3.2753574e+00 1
  4.7712125e-01  2.9208743e+00  3.3432116e+00 1
  5.7949778e-01  2.9896545e+00  3.4070338e+00 1
  6.8472870e-01  3.0713664e+00  3.4879157e+00 1
  7.9588002e-01  3.1485718e+00  3.5596553e+00 1
  8.9733563e-01  3.2217793e+00  3.6349103e+00 1
  1.0000000e+00  3.2849493e+00  3.7014212e+00 1
Rhea time - Temperature data e:\acb6b3078 geoff rowe\acb6b3078rtfo.ttd
File created 1/17/2008 9:32:22 AM
Isotherm details:
        Temp.   Points                Data
Number  C       used                  source
   1      5.0   11111111111111111111  e:\...\acb6b3078 rtfo 8mm.dow\T5.0
   2     15.0   11111111111111111111  e:\...\acb6b3078 rtfo 8mm.dow\T15.0
   3     30.0   11111111111111111111  e:\...\acb6b3078 rtfo 8mm.dow\T30.0
   4     45.0   11111111111111111111  e:\...\acb6b3078 rtfo residue.dow\T45.0
   5     60.0   11111111111111111111  e:\...\acb6b3078 rtfo residue.dow\T60.0
   6     75.0   11111111111111111111  e:\...\acb6b3078 rtfo residue.dow\T75.0
   7     90.0   11111111111111111111  e:\...\acb6b3078 rtfo residue.dow\T90.0
```

Running the Software

When the software is started either the file-handling window (Appendix A) will be displayed on the main analysis window. If the file handling window is displayed the user selects the button on the menu bar or uses the File menu on the Toolbar to switch to time-temperature superposition to run the analysis. When in t-T mode the user then selects the *.ttd file using the file menu of the file button. The default directory will be that most recently used to save data. Once a data set is opened the software automatically performs the calculation of the relaxation spectra and activates the graphing buttons that are applicable for the type of data as illustrated below, see Figure 2.

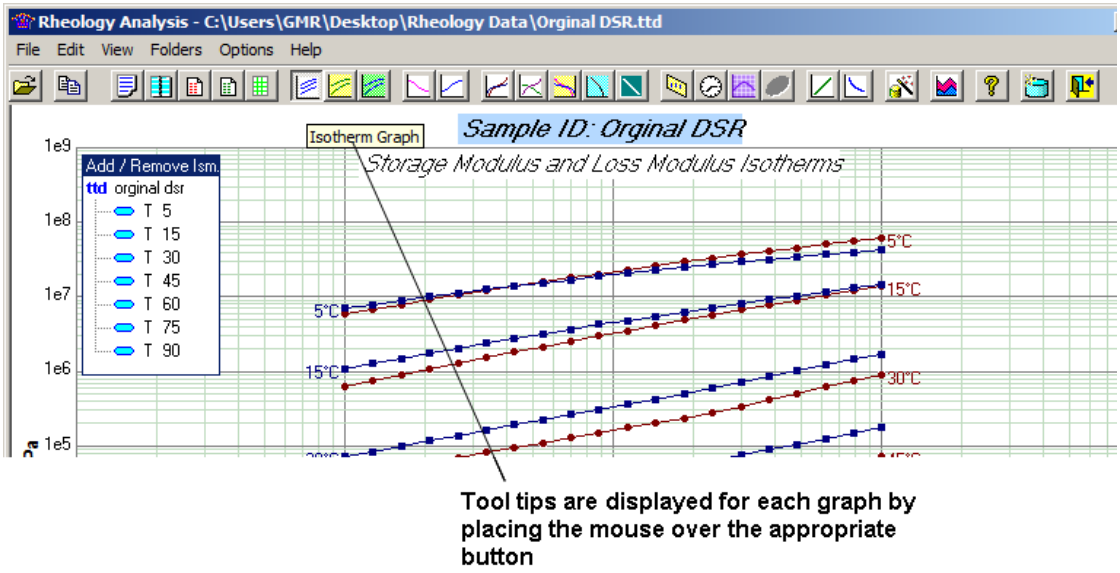


Figure 2: Graphic buttons and tool tips - main analysis window

Nomenclature

Different publications use different terminology and nomenclature for graphics. After review, this software has adopted the following:

G*	complex shear modulus
G'	storage shear modulus
G"	loss shear modulus
G(t)	creep shear relaxation modulus
J(t)	creep shear compliance
E*	complex extensional modulus
E'	storage extensional modulus

E"	loss extensional modulus
E(t)	creep extension relaxation modulus
D(t)	creep extension compliance
S(t)	stiffness - bending beam rheometer
λ_i	relaxation time
g_i	relaxation strength
Λ_i	retardation time
c_i	retardation strength
a_T	shift factor

Basic Graphic Plots

In the example illustrated below (Figure 3) a file has been read into the software which contains dynamic data. All dynamic graphs have become active (except one used for asphalt mix master curve – solid behavior) since the data can be analyzed according to visco-elastic principles.

The data set shown consists of five isotherms of data ranging from 5°C to 90°C

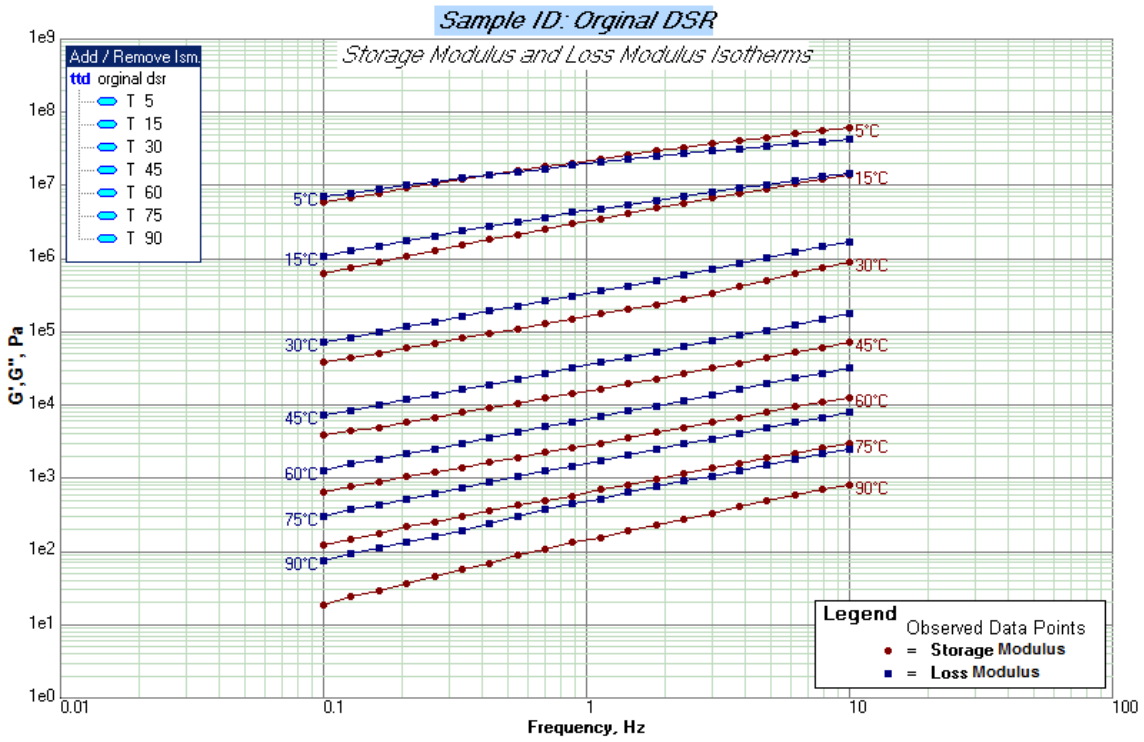


Figure 3: Isotherms collected for asphaltic binder sample, 5°C to 90°C

Automatic plots are generated for each graph - see examples below (Figure 4 to Figure 16). The graphs provided are as follows:

1. Isotherms - format as measured data.
2. G' Pairwise shift
3. G" Pairwise shift
4. Transient Modulus Stiffness Master Curve Graph (for this data example - G(t) versus t)
5. Transient Compliance Master Curve Graph (for this data example J(t) versus t)
6. Storage and Loss Modulus Master Curve Graph (for this example G' and G" versus frequency)
7. Complex Modulus and Phase Lag Master Curve Graph (for this example G* and δ versus frequency)
8. Viscosity Master Curve Graph
9. G* versus δ - Black space
10. Dobson Master Curve Graph
11. Frequency vs. Temperature (area of interpolation obtainable)
12. Isochrone Graphs
13. Oberst Analysis Graph
14. MEPDG (Mechanistic-Empirical Pavement Design Guide Master Curve Graph – only applicable to materials with VE-solid behavior – not this example)
15. Arrhenius shift factors
16. WLF shift factors

The relaxation times are plotted on the master curve and the black space plots. The shifting parameters are plotted in the Arrhenius and WLF form

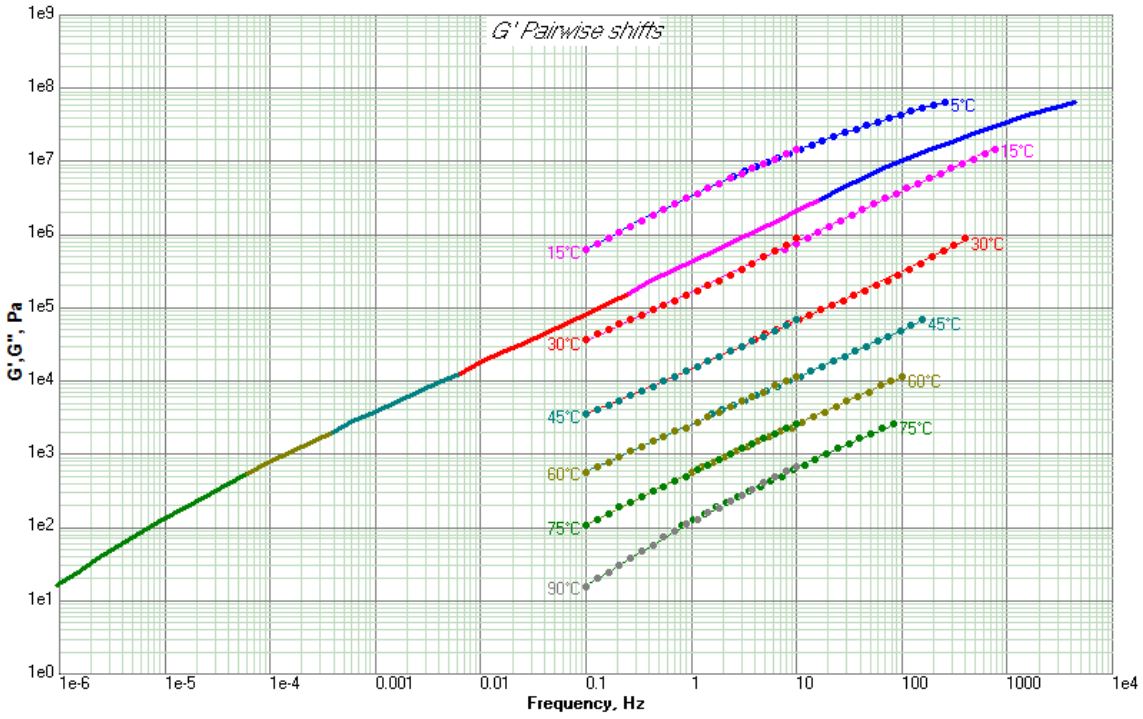


Figure 4: G' Pairwise shifts

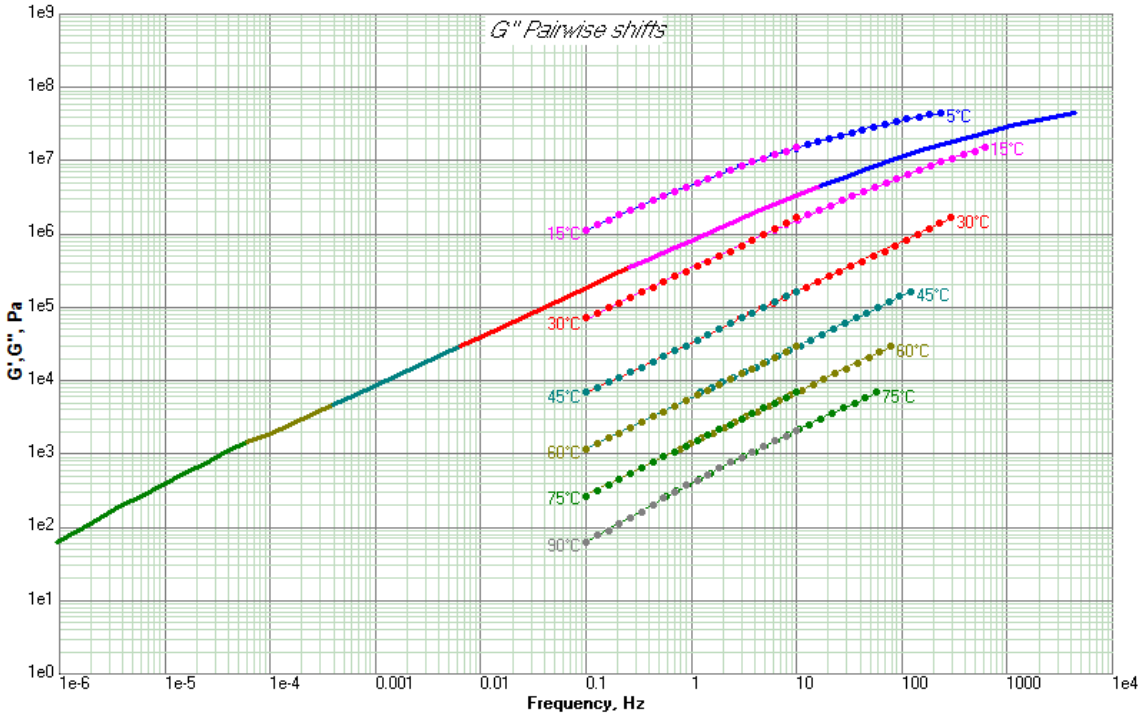


Figure 5: G" Pairwise shifts

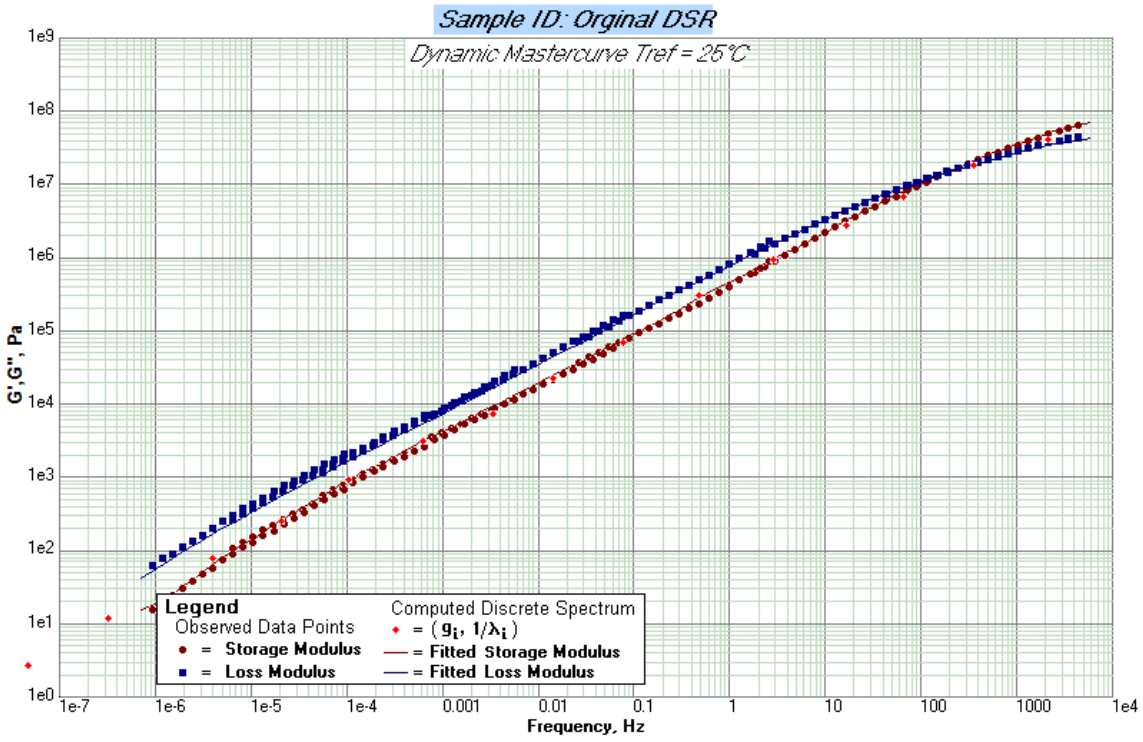


Figure 6: Master curve of G' and G" for asphaltic binder sample

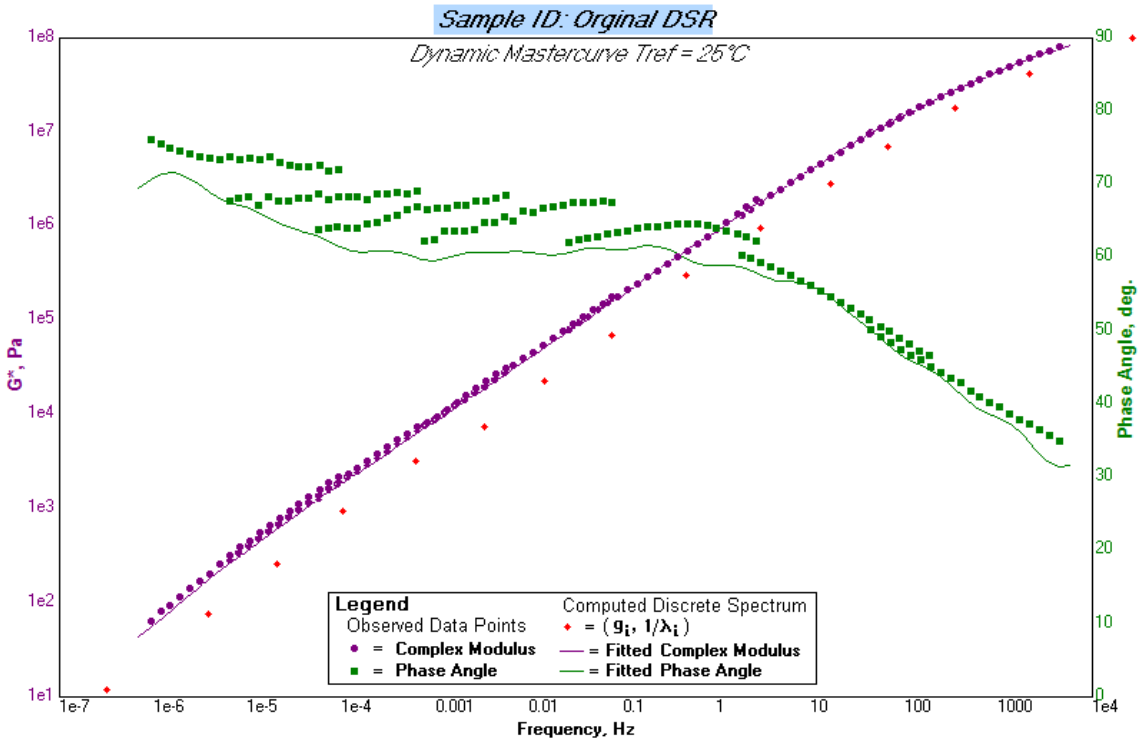


Figure 7: Master curve of G* and δ for asphaltic binder sample

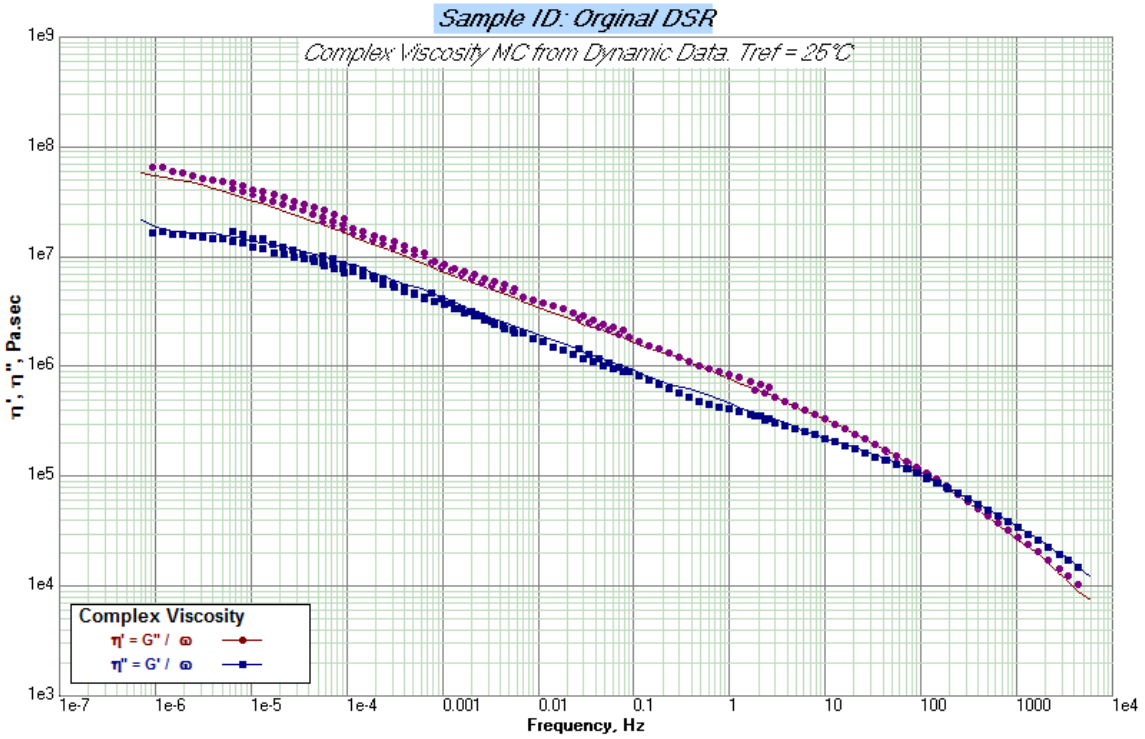


Figure 8: Complex Viscosity MC from Dynamic Data

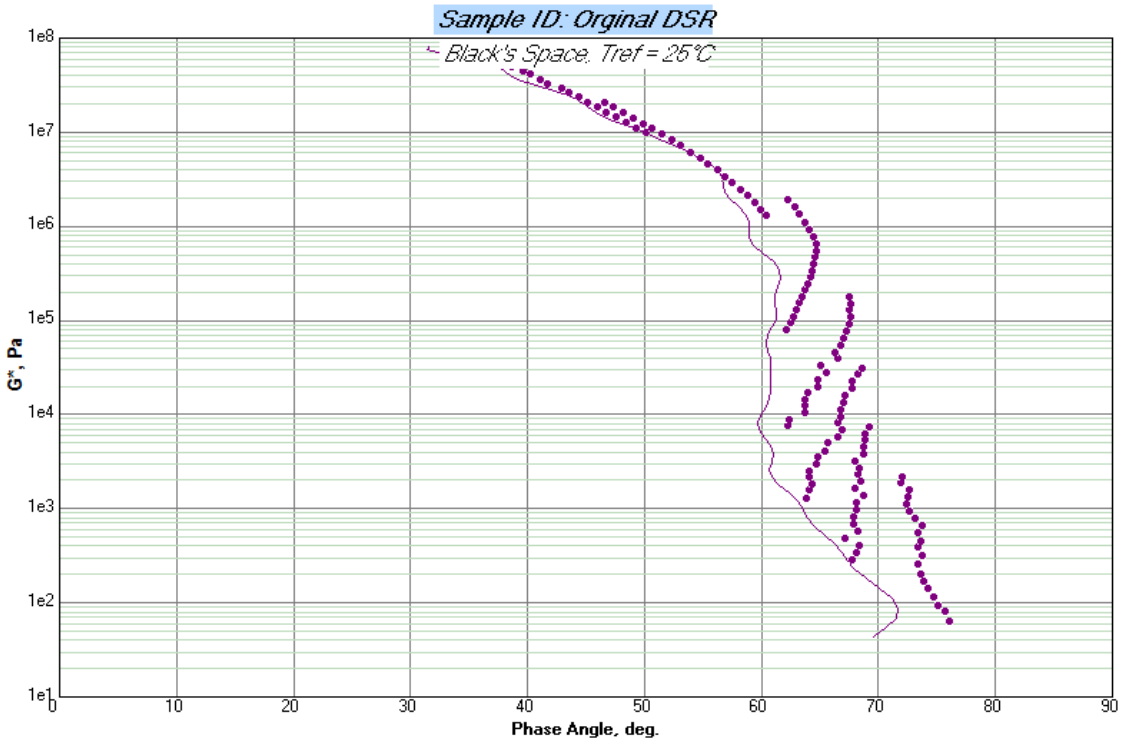


Figure 9: "Black's space" (Phase Angle vs. G*) for asphaltic binder sample

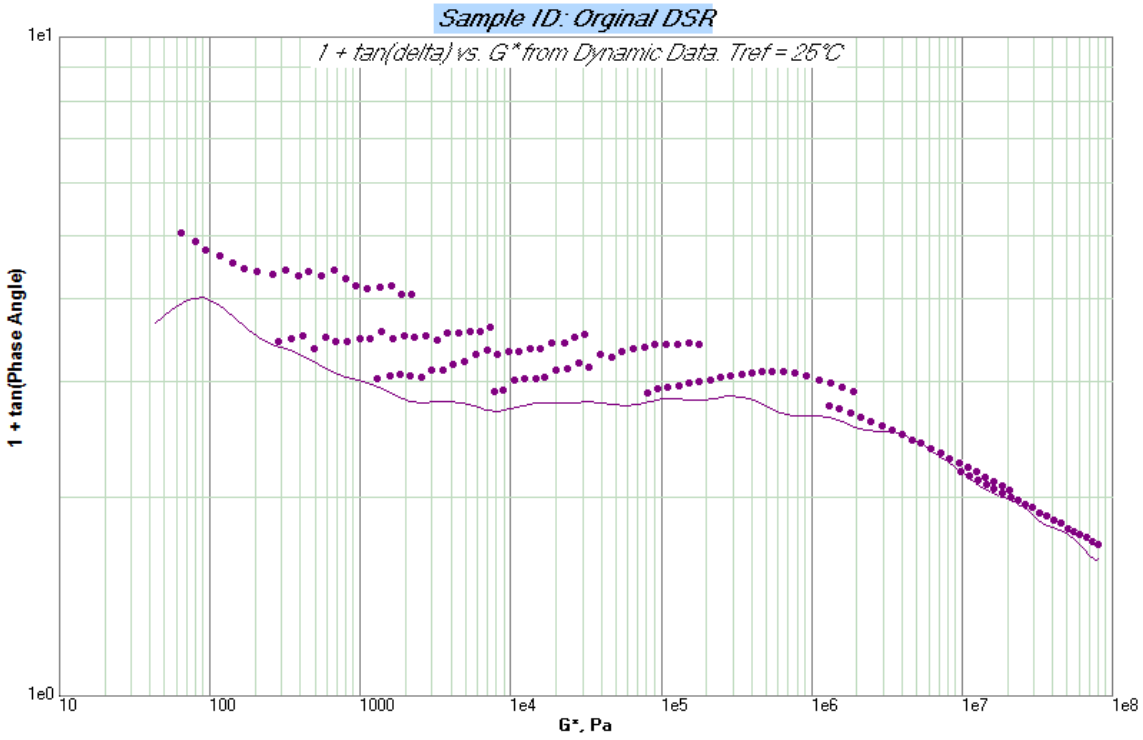


Figure 10: Dobson Master Curve Graph – plots 1+tan(δ) vs. G*

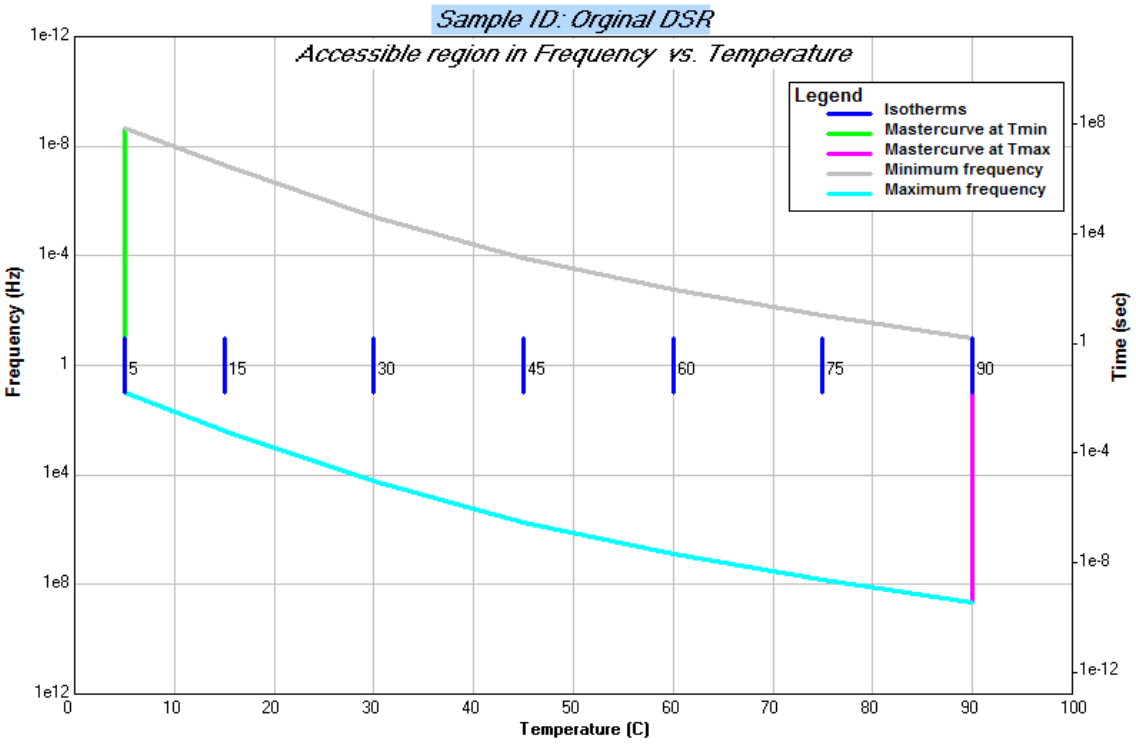


Figure 11: Data collected and range over which data can be interpolated from look up feature

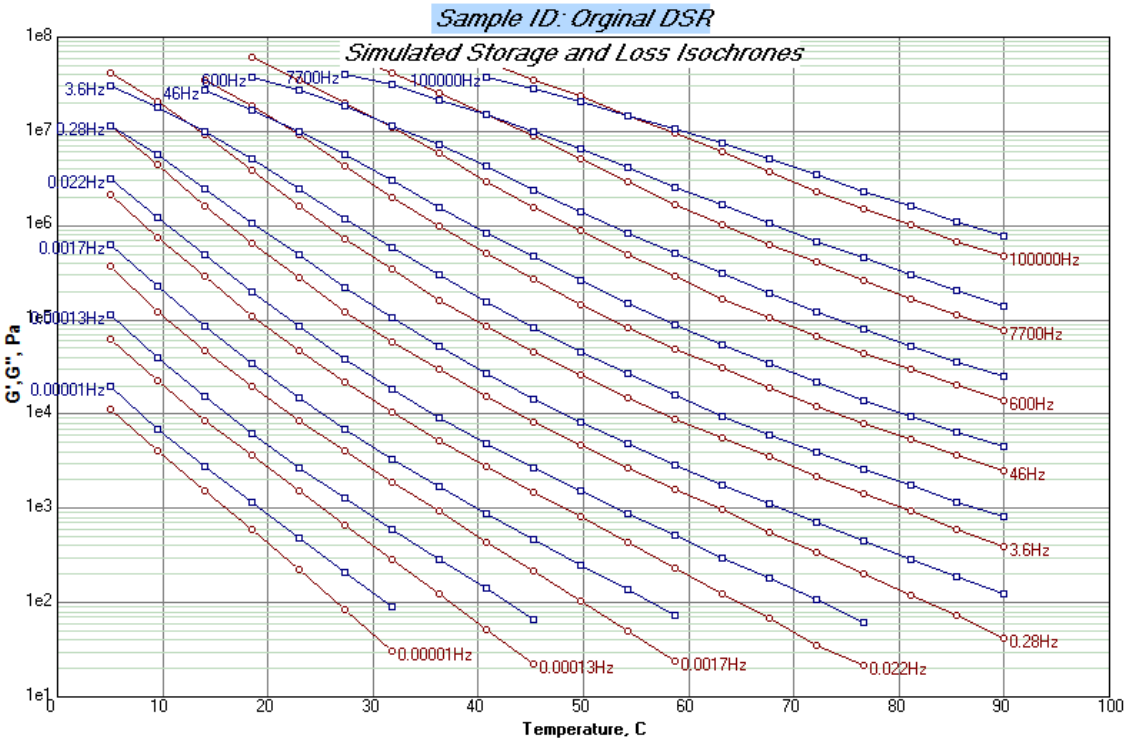


Figure 12: Simulated Isochrones from isothermal data – Isochrones can be choice of 4 different parameter sets

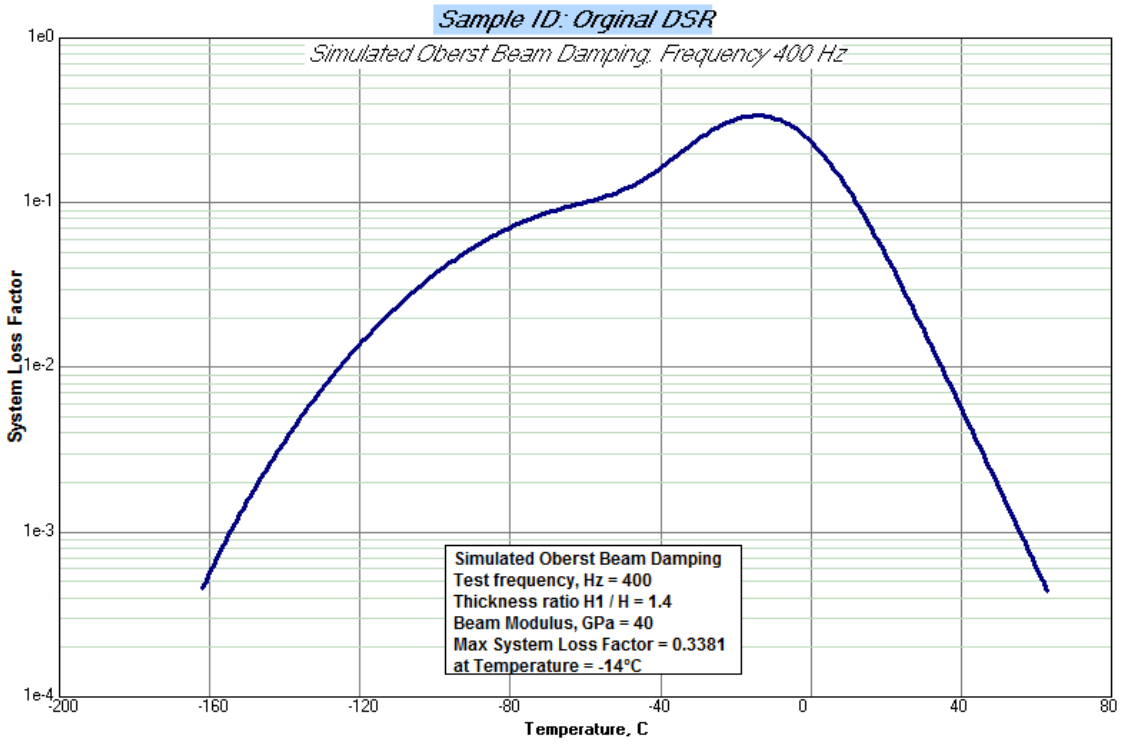


Figure 13: Simulated Oberst Beam Damping Properties

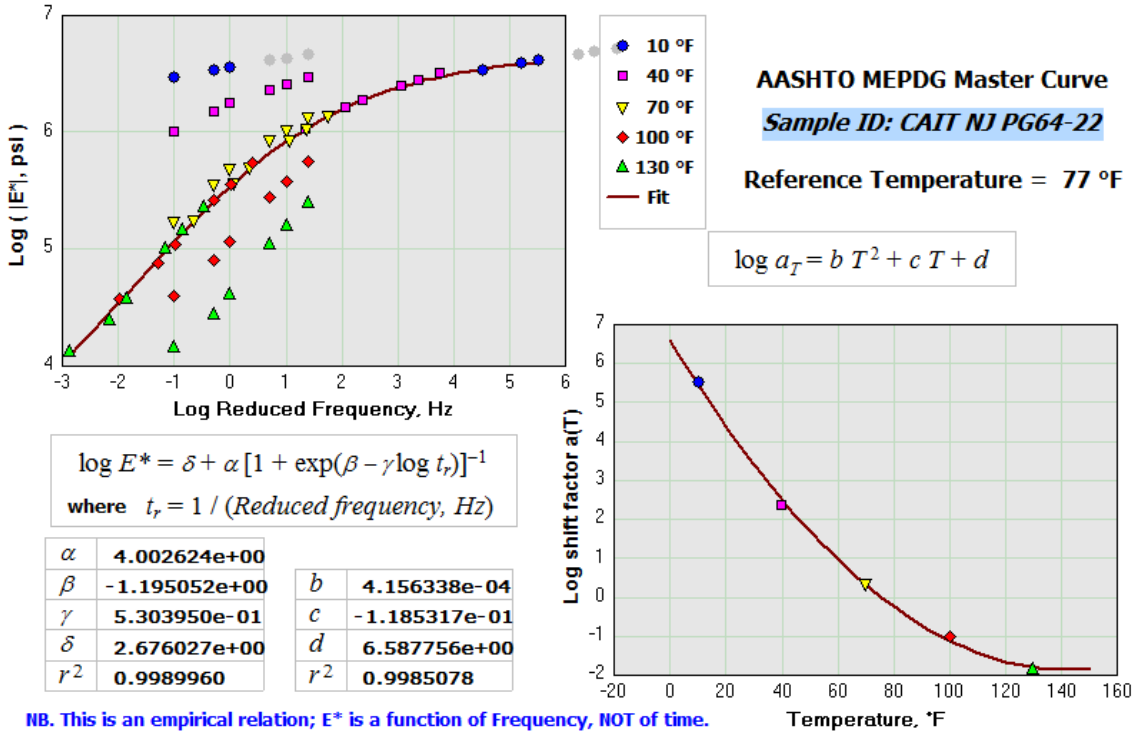


Figure 14: AASHTO MEPDG Master Curve Data - taken from Mixture data set developed by CAIT at Rutgers University, NJ

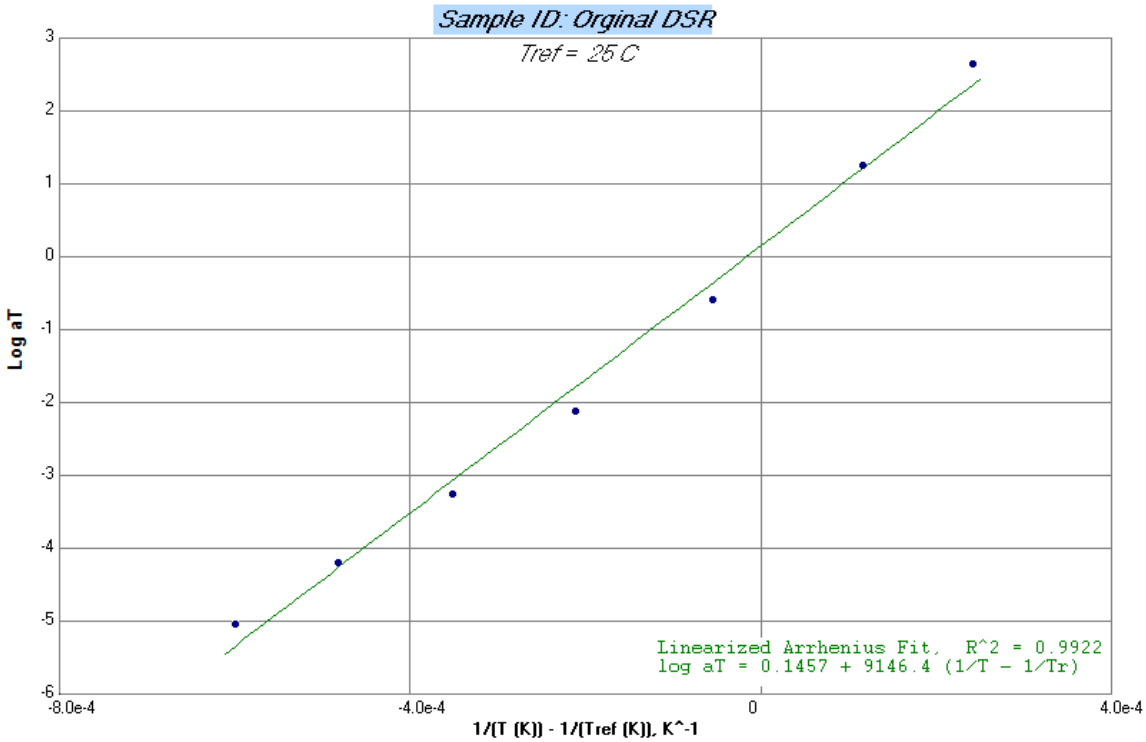


Figure 15: Linearized Arrhenius Fit to Shifting

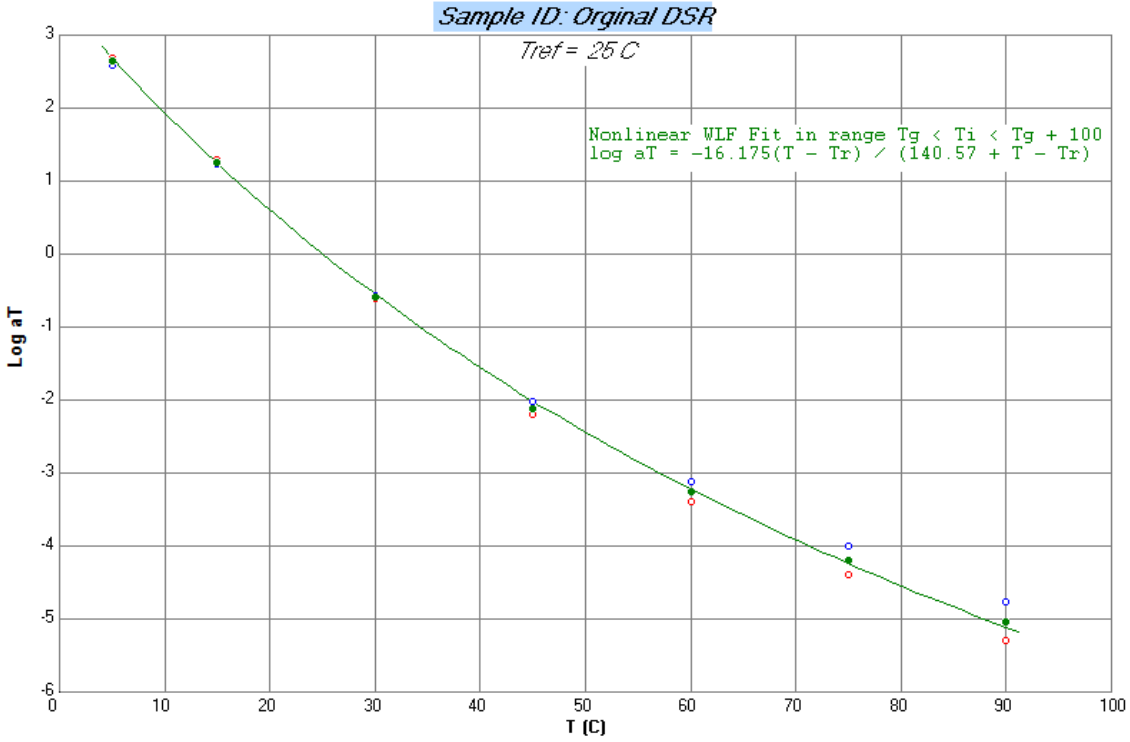


Figure 16: Nonlinear WLF Fitting Parameters

Look up feature

A critical aspect of rheology and analysis of data is to allow rapid estimation of visco-elastic properties at temperatures and frequencies other that those at which the data is collected. A look up feature is provided that enables time and frequency domain properties to be estimated for the active data set, see Figure 17. The user enters the required frequency, temperature and time and activates the run button.

All common visco-elastic properties are immediately displayed for the stipulated conditions.

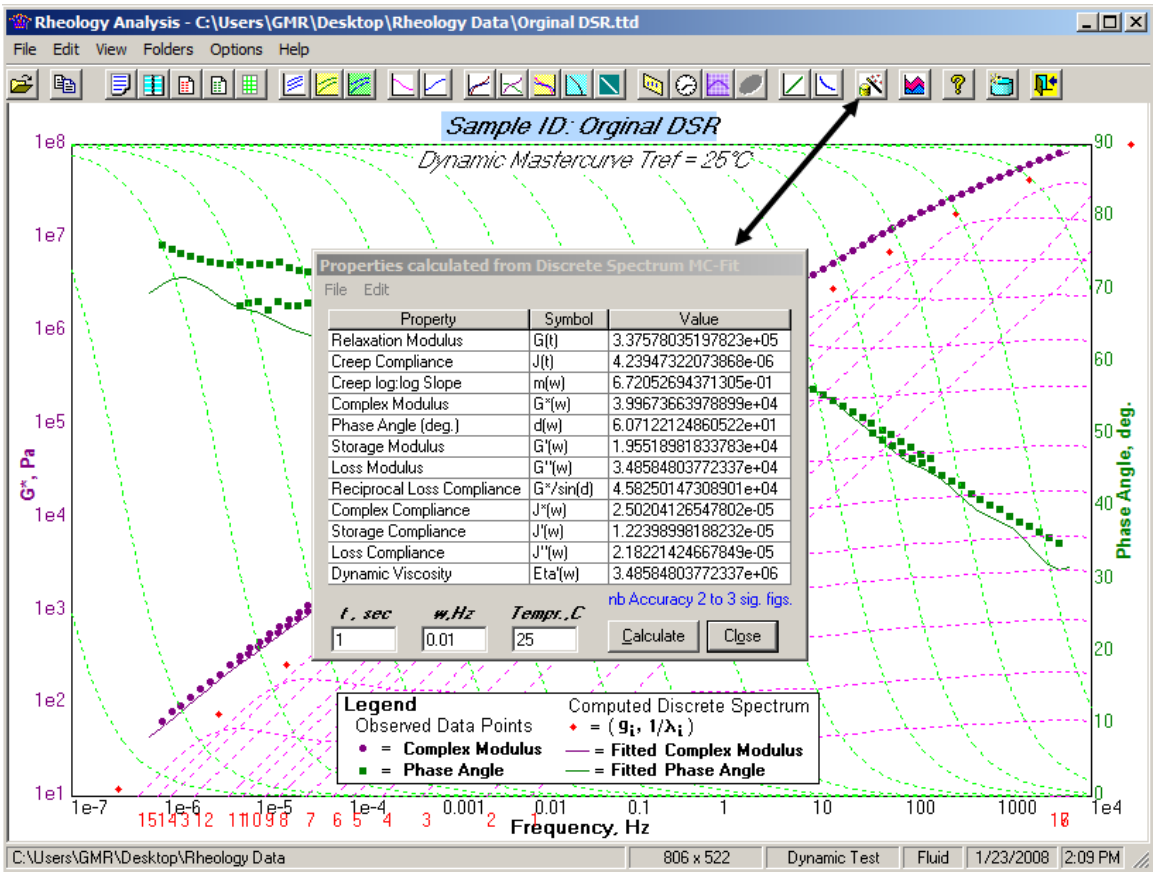


Figure 17: Look up feature

Advance Graphing

RHEA™ users can make use of advance graphing features to develop sophisticated graphic plots. This utility can be activated from an additional button provided on the menu bar as illustrated below. The graphic utility contains its own help menu and pop-up features for various part of the graph.

When this button is activated the program sends the contents of the active graph to the graphing application without interfering with the calculation in **RHEA™**. *This feature is available for nine of the thirteen automatic graphs.* The user can then save the "**graph data**" -or- "**graph data and graph format**". Once multiple data sets have been saved the user can then superimpose data sets of the same kind using the superimpose item on the Edit menu

Each feature of the graph can be changed by activating the "2D Chart Control Properties" dialog with a right mouse click. The general box is illustrated below in Figure 18 with the advanced graphing activated for a master plot of complex modulus and phase angle. However, if you activate this dialog box when the mouse is located over a graphic feature - a limited box relating only to that item or feature will be displayed.

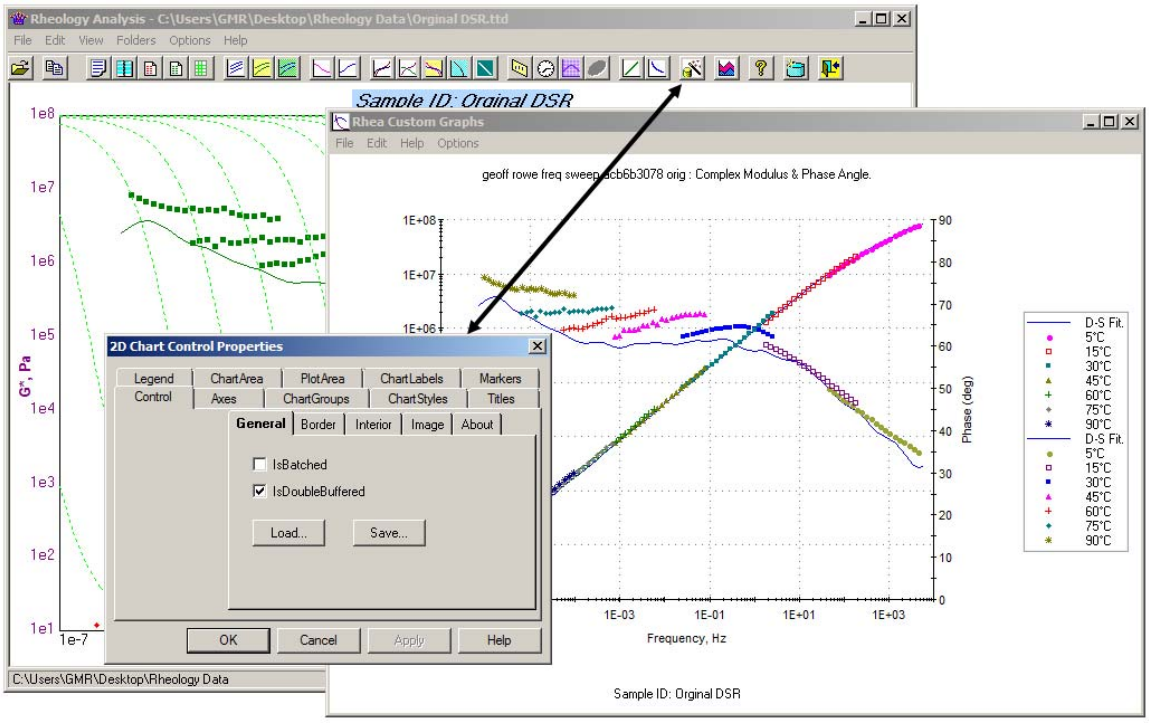


Figure 18: Advanced graphing controls

After several data sets have been superimposed it is possible to change styles and edit the default text that has been posted to the various dialog boxes to develop complex graphs as illustrated below. Detailed information is provided in the HELP file.

In addition, to the graphics capabilities of **RHEA™** it is possible to copy the graphics into other applications as either enhanced meta files or bitmap formats. The meta file format can be converted into other formats by the user if other installed software supports this format (for example Power Point).

Isotherm Contributions

A feature is provided to allow the user to rapidly view the contributions that an individual isotherm has in the master curve by using a separate symbol and color for each isotherm. This feature is available for most of the plot formats and is activated by placing the mouse over a master curve graph and using the "right click."

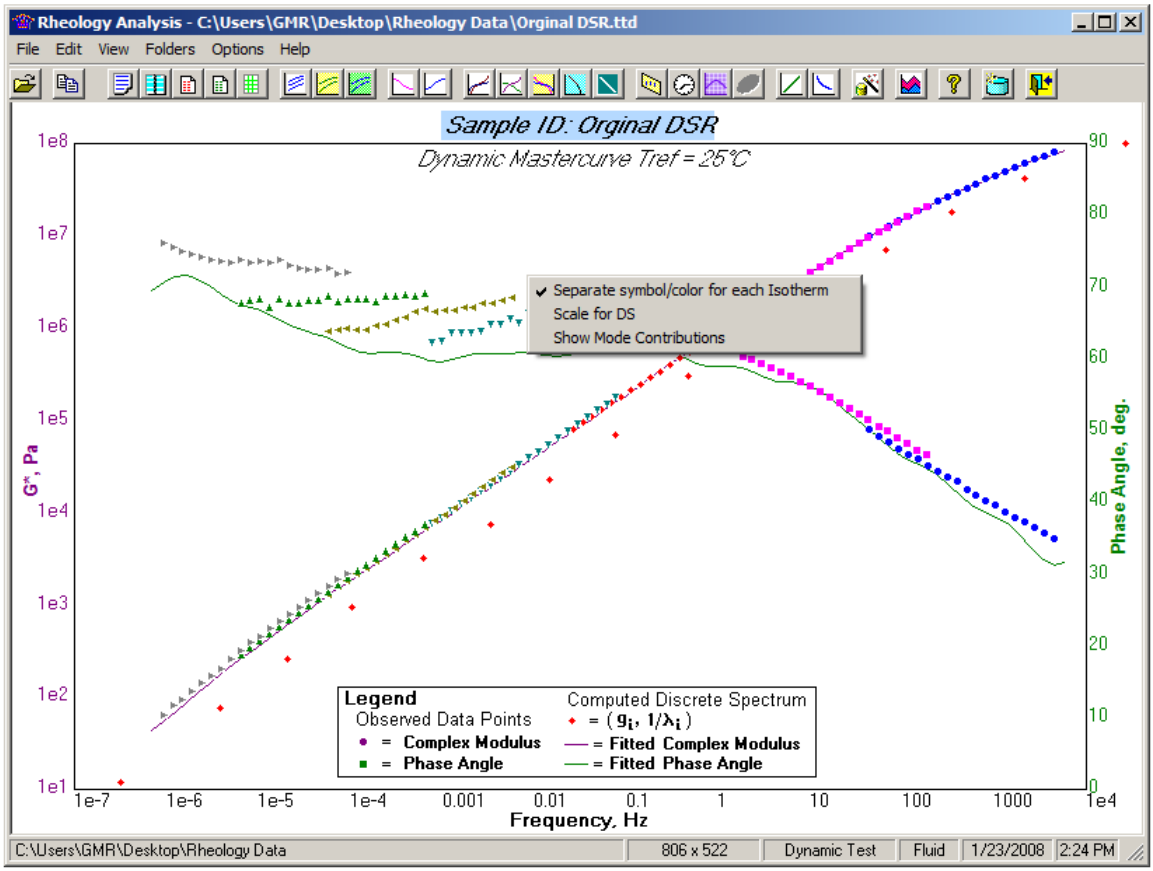


Figure 19: Separate symbol and color for each isotherm

Examples

Estimation of binder property

A binder sample has been collected and tested at temperatures illustrated below. The user wants to determine the SHRP intermediate binder property at various temperatures associated with the fatigue specification, i.e., 10, 13, 16, 19, 22, 25 and 28°C (at 10 radians/second).

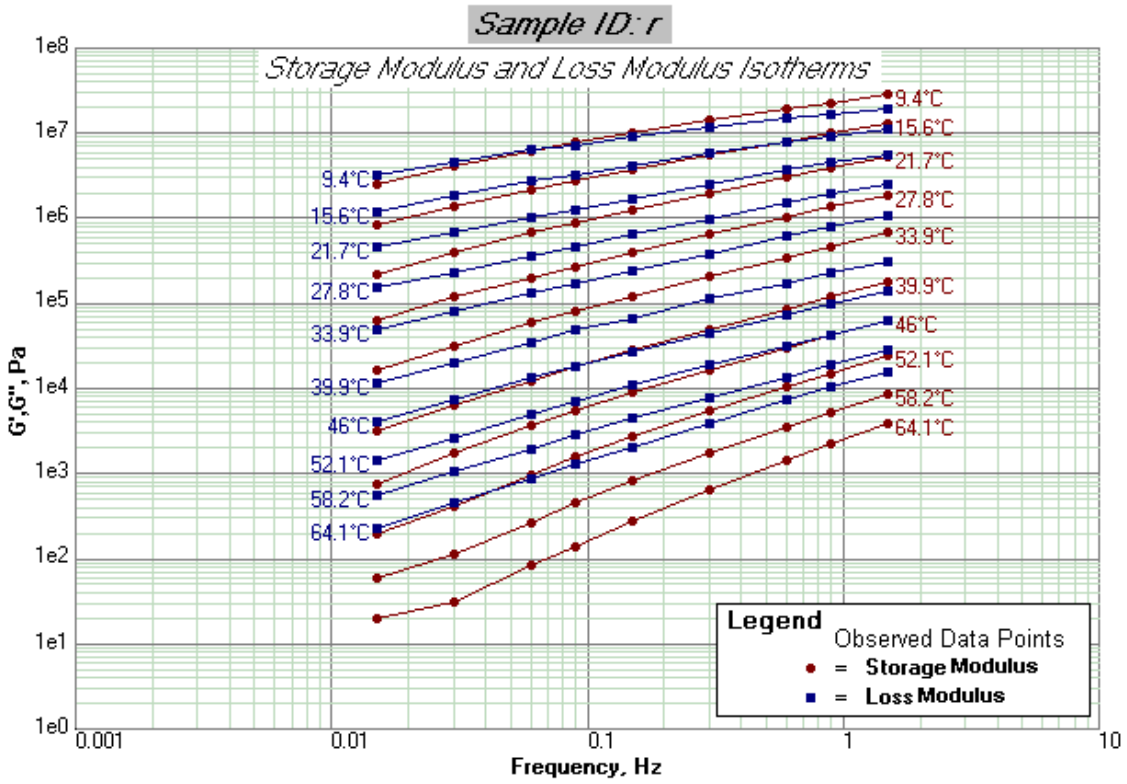


Figure 20. Isotherms of binder stiffness ranging from 9.4 to 33.9°C

Using the look-up feature the user obtains properties at the desired temperatures.

Temperature, °C	G*sinδ (kPa)
10	20,049
13	14,821
16	10,919
19	7,797
22	5,478
25	3,702
28	2,442

*Note: G*sinδ = G"*

This information is then graphed (using other software such as EXCEL) to allow the user to investigate the sensitivity of this binder to this specification parameter with temperature. The maximum allowed value in the specification is 5,000 kPa.

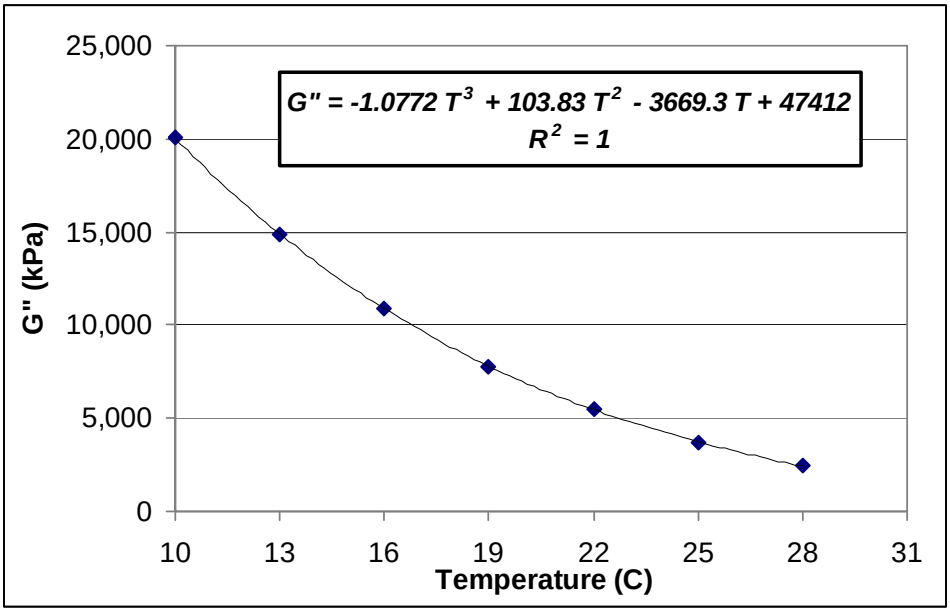


Figure 21. Relationship between G" (kPa) and temperature (°C)

In this example the effect of the binder temperature on the specification parameter can be clearly obtained. The binder meets requirements at 25°C and above while at other temperatures it fails the test requirement.

Visco-elastic information for advanced pavement design

Engineers designing pavement structures use visco-elastic pavement design. Several methods of design exist which require data in the form of relaxation and retardation spectra (Rowe et. al, 1995; Huang 1993). The **RHEA™** software presents this information based upon the data set collected in formats that can be used in the referenced methods.

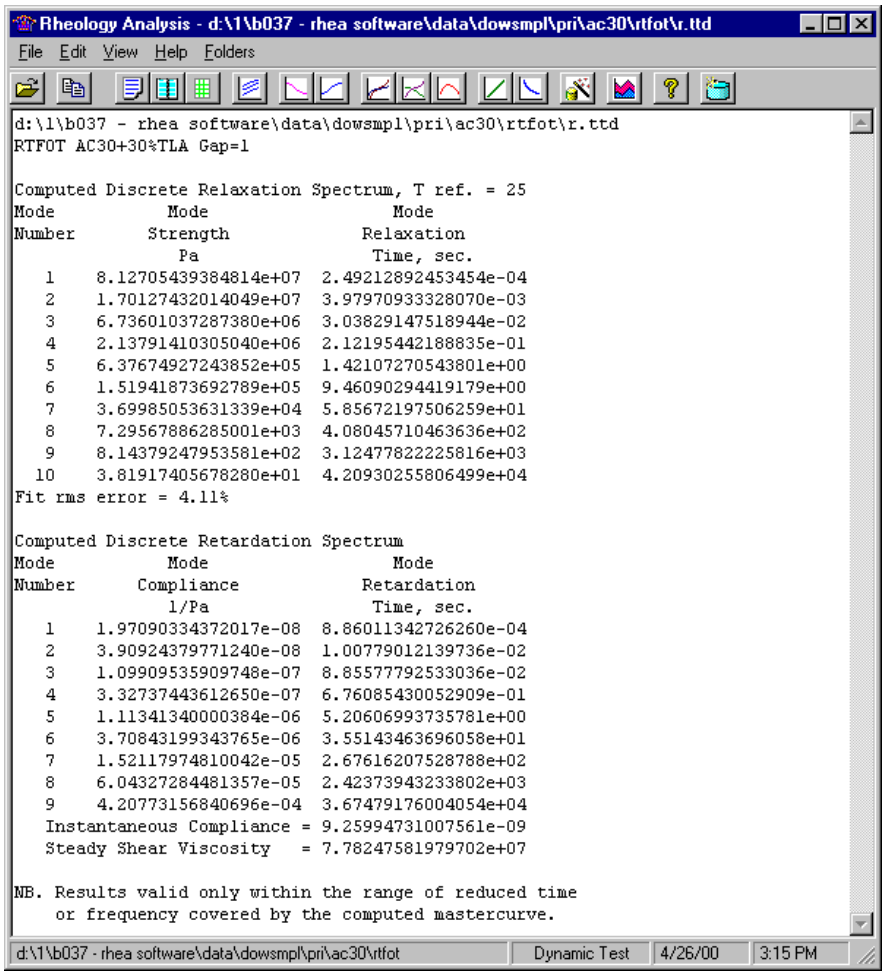


Figure 22: Relaxation and Retardation Spectrum

Frequency Sweep at Constant Height

The frequency sweep test at constant height is used for permanent deformation and fatigue cracking analysis in the Superpave procedures (The Asphalt Institute, SP-2, 1996). A repeated shearing load is applied to the specimen to achieve a shear strain of 0.05%. The test is carried out over a range of frequencies, 10 to 0.01 Hz.

The data is prepared in the format illustrated earlier resulting in isotherms of stiffness. In the Superpave specification stiffness information is required at temperatures which are site dependent for the intermediate analysis level (T_{eff}(PD) and T_{eff}(FC))[1] or for the complete analysis at 4, 20 and 40°C.

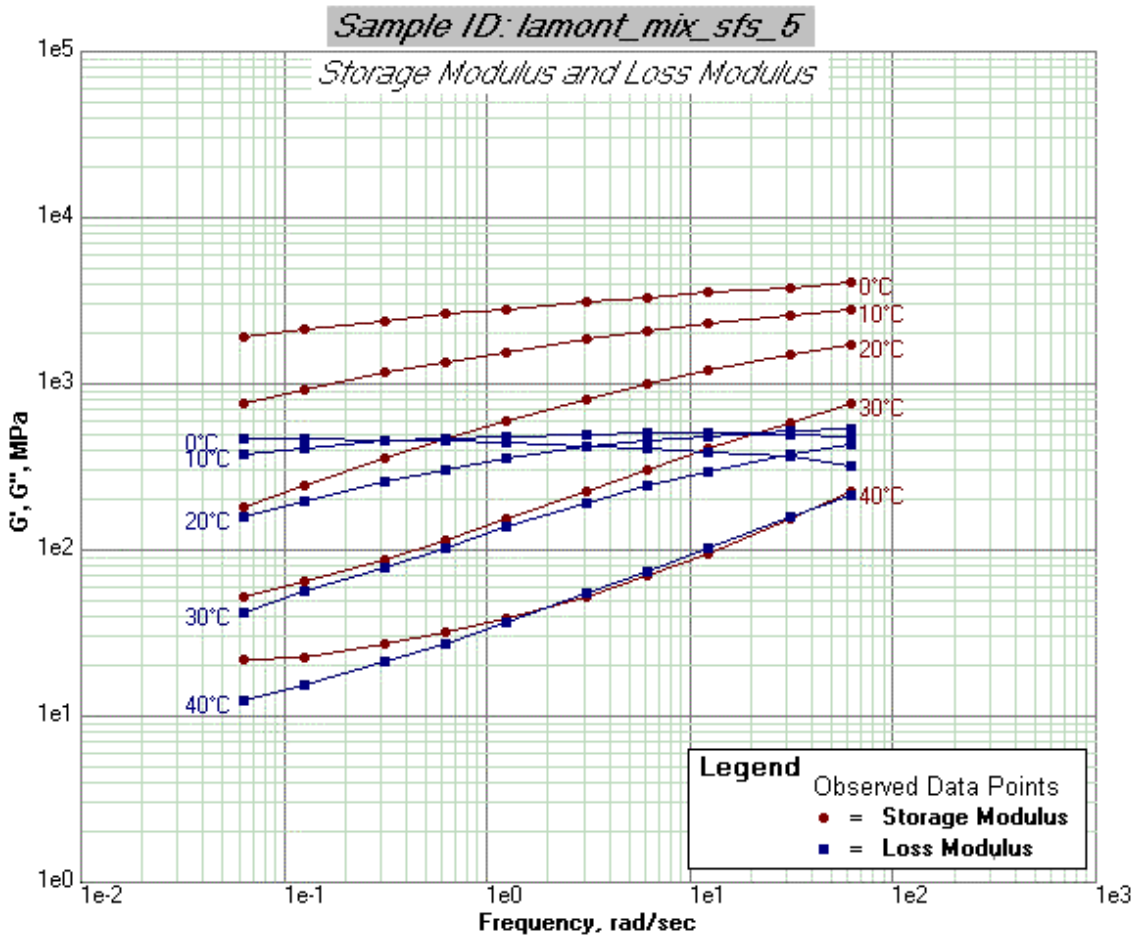


Figure 23: Frequency sweep test at constant height, isotherms, asphalt mixture results

Cominsky (1994) proposed the following relationship for T_{eff}(FC):

$$T_{eff}\,(FC) = 0.8(MAPT) - 2.7$$

[1] T_{eff}(FC) is the single temperature at which an equal amount of fatigue damage would occur to that measured by considering each season separately throughout the year. T_{eff}(PD) is the single temperature at which the predicted permanent deformation would be identical to that predicted by a multiple temperature analysis.

MAPT is defined as the mean annual pavement temperature. For a particular location the MAPT is estimated as follows:

"The temperature for the Tacoma area in the SHRP 10-year database is illustrated below. Using this data the effective temperature for pavement design can be determined to be 10.2°C (50.4°F)."

Month	t min	t max	std. t min	std. t max	MMAT	std. Mean	Pave Temp
Jan	1.1	7.8	4	3.5	4.5	3.8	8.3
Feb	2.4	10.2	3.1	2.9	6.3	3.0	10.4
Mar	3.2	12.2	2.9	3.4	7.7	3.2	12.0
Apr	4.9	15.2	2.9	4.1	10.1	3.5	14.7
May	7.6	18.8	2.3	4	13.2	3.2	18.4
Jun	10	21.2	2.4	4	15.6	3.2	21.1
Jul	12.2	24.5	1.9	3.8	18.4	2.9	24.3
Aug	12.8	24.7	1.9	4.1	18.8	3.0	24.7
Sep	10.9	21.6	2.1	4.1	16.3	3.1	21.9
Oct	7.5	16.6	2.9	3.8	12.1	3.4	17.0
Nov	3.9	11.3	3.6	3.2	7.6	3.4	11.9
Dec	2.2	8.6	4	3.7	5.4	3.9	9.4
						AAPT =	16.2
						Teff (FC)	10.239667

Note: All data in degrees Celsius.
Record period was 1971 to 1981.
Latitude 47.25 degrees North, 122.43 degrees W, Elevation 82.33 meters.
Weather station reference - Tacoma WB City WA8286

By setting the reference temperature to 10.2°C the properties at this pavement design temperature are determined. The graphs below illustrate the various results.

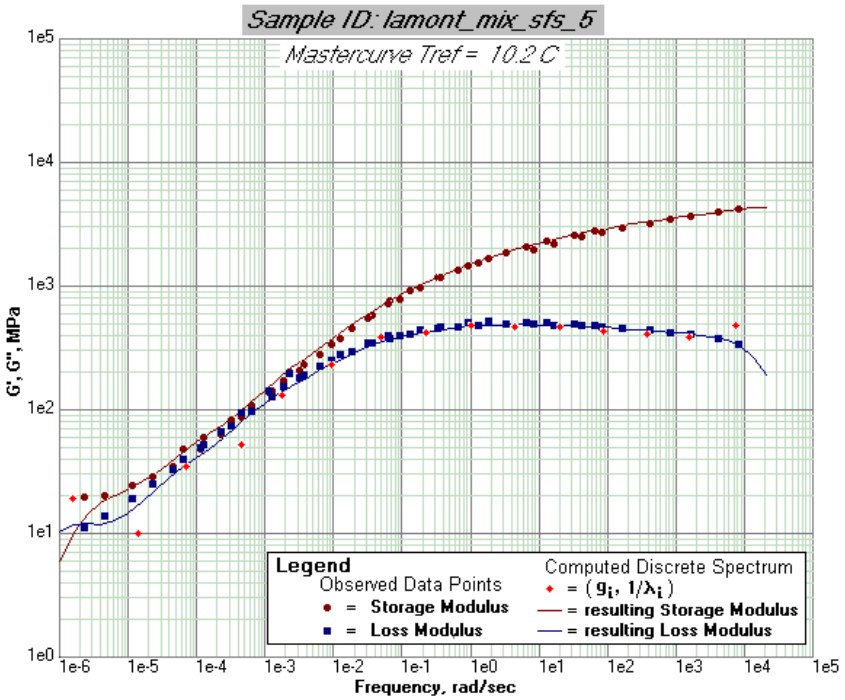


Figure 24: Frequency sweep test at constant height, G' and G" and fitted curves

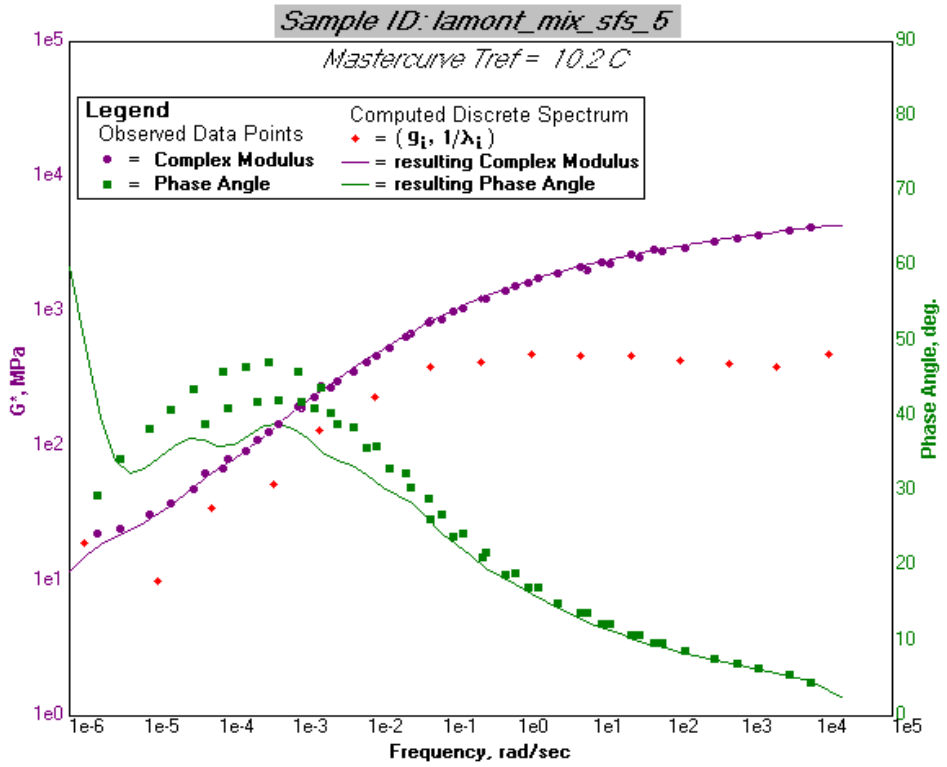


Figure 25: Frequency sweep test at constant height, G* and phase angle and fitted curves

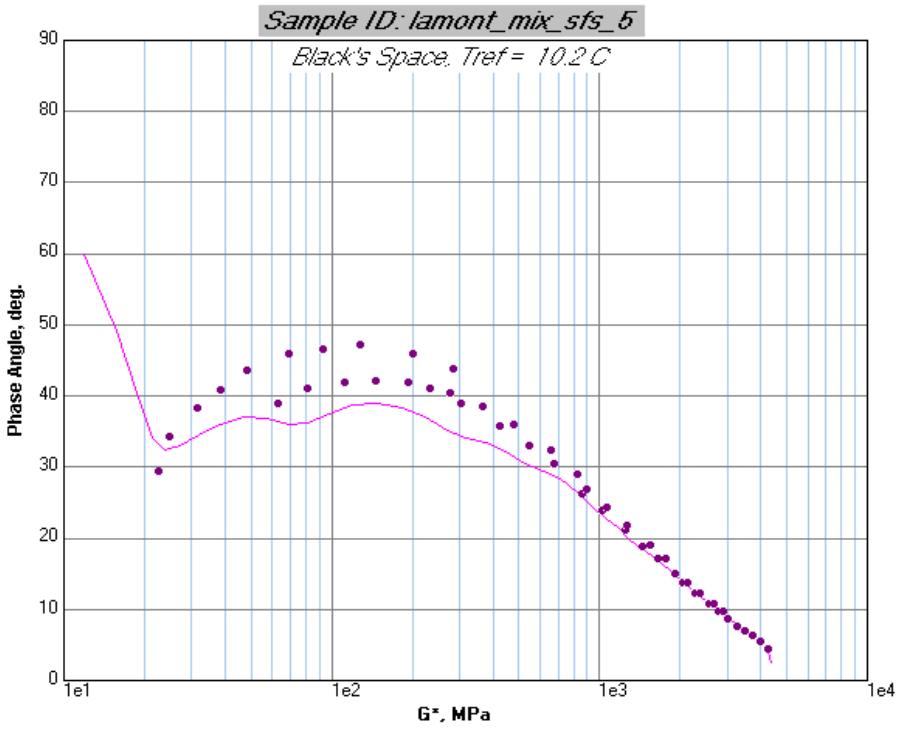


Figure 26: Frequency sweep test at constant height, Black Space plot

By inspection of the graphics it can be noted that at the highest temperature tested (40°C) (i.e. at the lowest frequencies) some non-linear visco-elastic behavior is occurring. The user has two options for improving the data analysis in this region, as follows:

1. Fit functional model to data before performing the analysis of the relaxation and retardation spectra.
2. Remove data set at high temperature, which appears to be the cause of the problem.

In this example we have opted for solution number 2 which gives the following black space diagram.

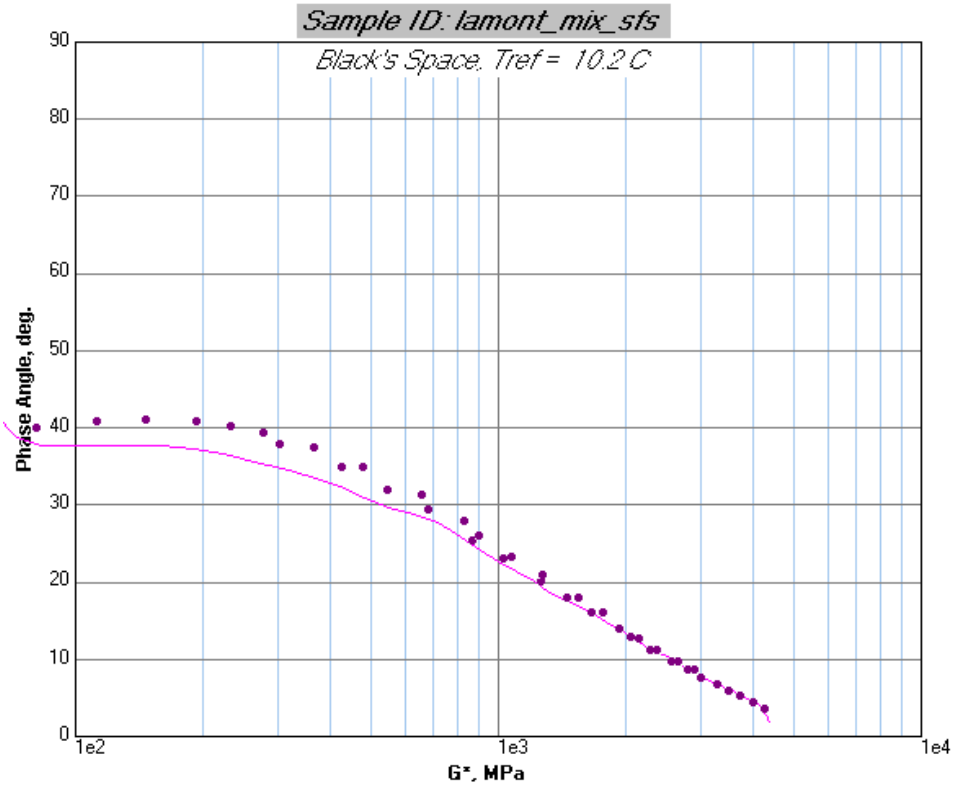


Figure 27: Frequency sweep test at constant height, Black space plot with one isotherm removed

This solution improves the appearance of the results. However, users must be cautioned that the analysis will only be as good as the collection of the original data. For asphalt mixtures non-linear behavior does occur and this becomes more significant as temperatures are increased.

Combination of BBR and DSR data sets

The Superpave binder specifications make use of two test devices for determining binder rheology; the Bending Beam Rheometer and the Dynamic Shear Rheometer. The BBR measures low temperature stiffness in the time domain while the DSR measures stiffness over a range of frequencies at higher temperatures. The RHEA™ software enables engineers and asphalt technologists to combine the data and represent it in either the time or frequency domain. The example shown below is test data recorded from Lamont test section 1. Figure 18 illustrates the G', G" versus frequency plot while Figure 19 illustrates the transformation to G(t).

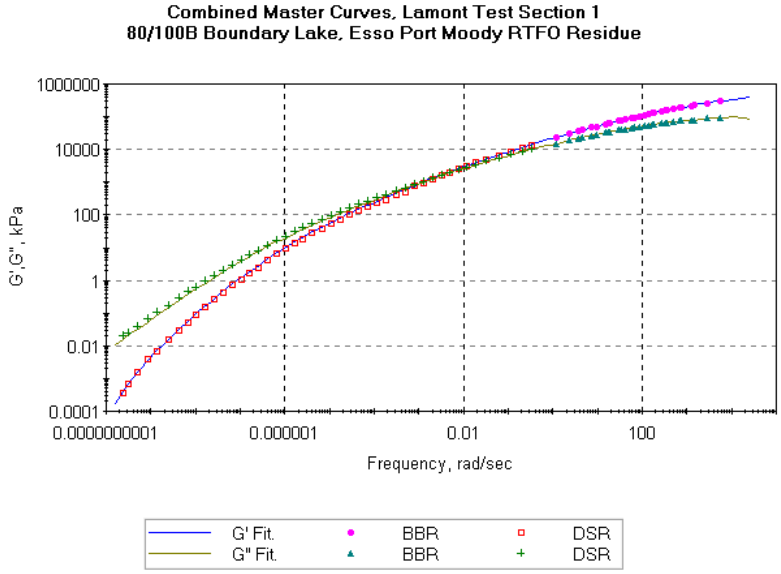


Figure 28: G', G" versus frequency - BBR and DSR combined data set, Lamont Section 1

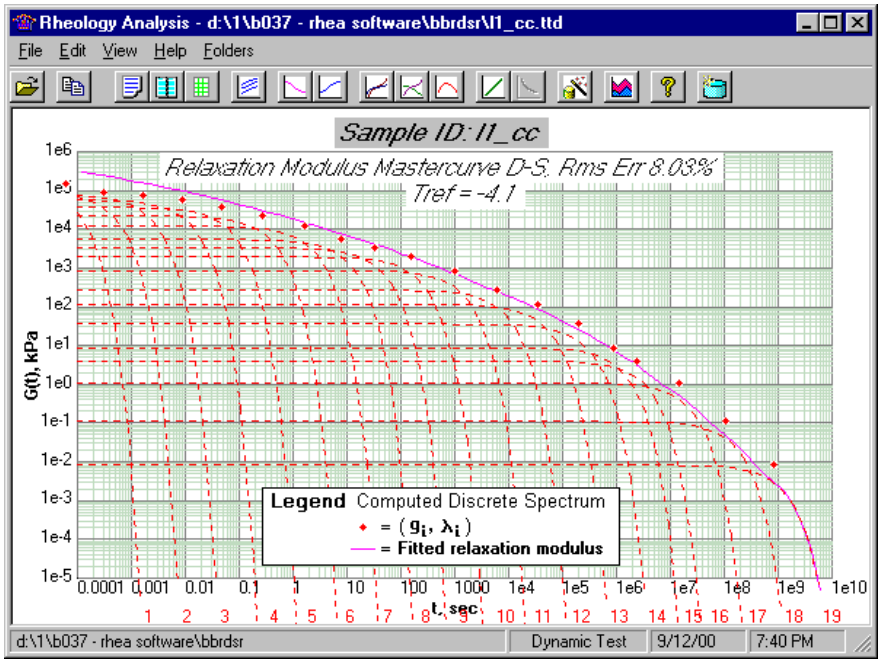


Figure 29: G(t) from combined data set, Lamont Section 1

Performing the combination

Summary of Procedure

1. The BBR data is fitted with the CA, CAS and CAM model (Rowe et al., 1999) and the software determines the fit with the lowest error. This master-curve is adopted.

2. Hopkins and Hamming method is used to convert the master curve to the relaxation modulus E(t).
3. The E(t) data is then fitted with a CAM model using the Glassy modulus determined from the previous fitting. This gives a function which describes a E(t) fit.
4. The discrete spectra is calculated for the E(t) fitted function.
5. The reciprocal of the observed times are the substituted into the function to estimate the E', E" data points.
6. The data points are shifted using the original shift values obtained along with a reverse density correction to obtain dynamic isotherms corresponding to the original data.
7. Extensional data is then output to a data file converting to G in the process with an optional Poisson's ratio (default is set at 0.5).

Steps in the Performing the Analysis

The user should develop a BBR data set in the normal manner. The example illustrated below is the data obtained for the Lamont study (Rowe et al., 2000) which contains five isotherms.

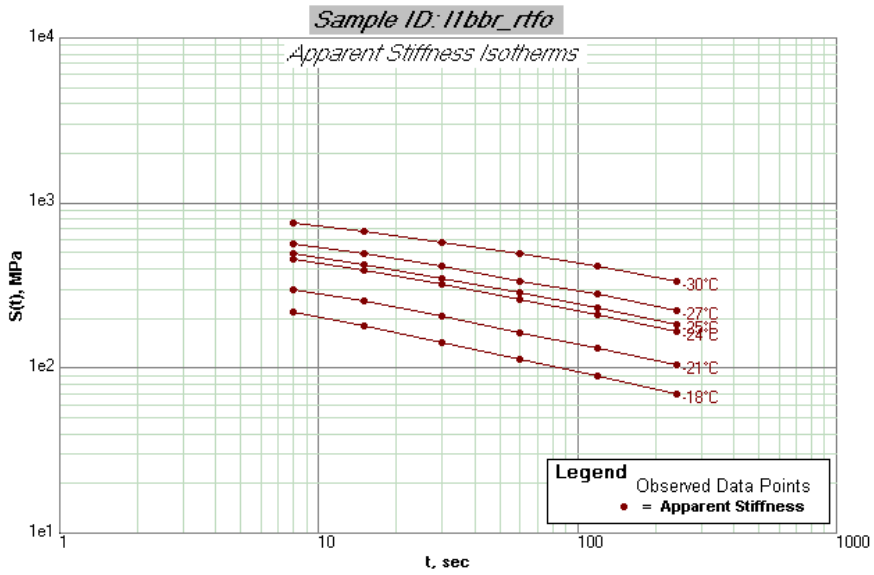


Figure 30: Isotherms of Stiffness from the BBR

The user should display the graph with the conversion to the dynamic form and use the right mouse to bring up the menu as shown. The "Pseudo Points" can be shown and then saved as an isotherm in a separate file.

[Note - the graphical representation states G' and G" - however - the data is E' and E" - we will be altering the axis in the next release].

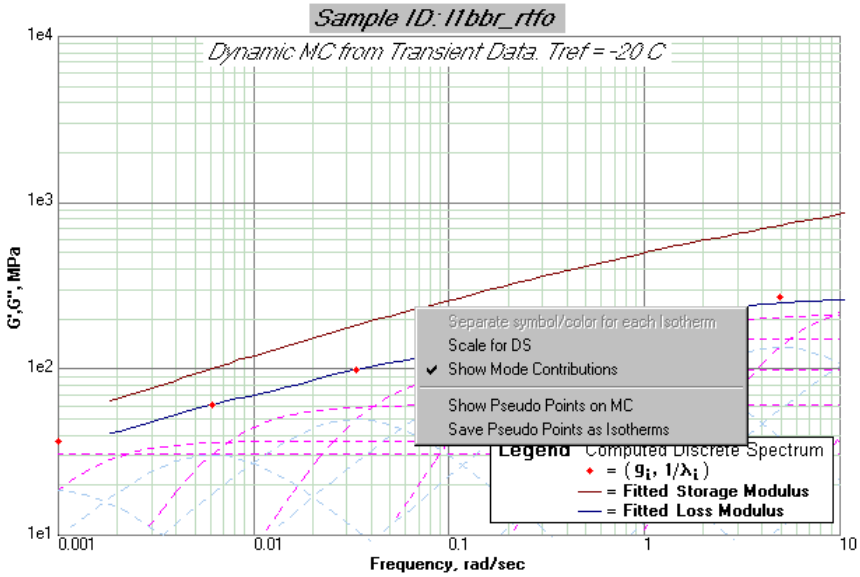


Figure 31: Calculated Dynamic Properties for a BBR Data Set

When saving the data the dialog box as illustrated is obtained. The user is prompted with a file name which has the extension "-pp.ttd" which indicates **p**seudo **p**oints output. The user can also change the default value of 0.5 for the Poisson's ratio at this stage. The data is then stored as equivalent DSR data sets for each of the temperatures in the BBR data files.

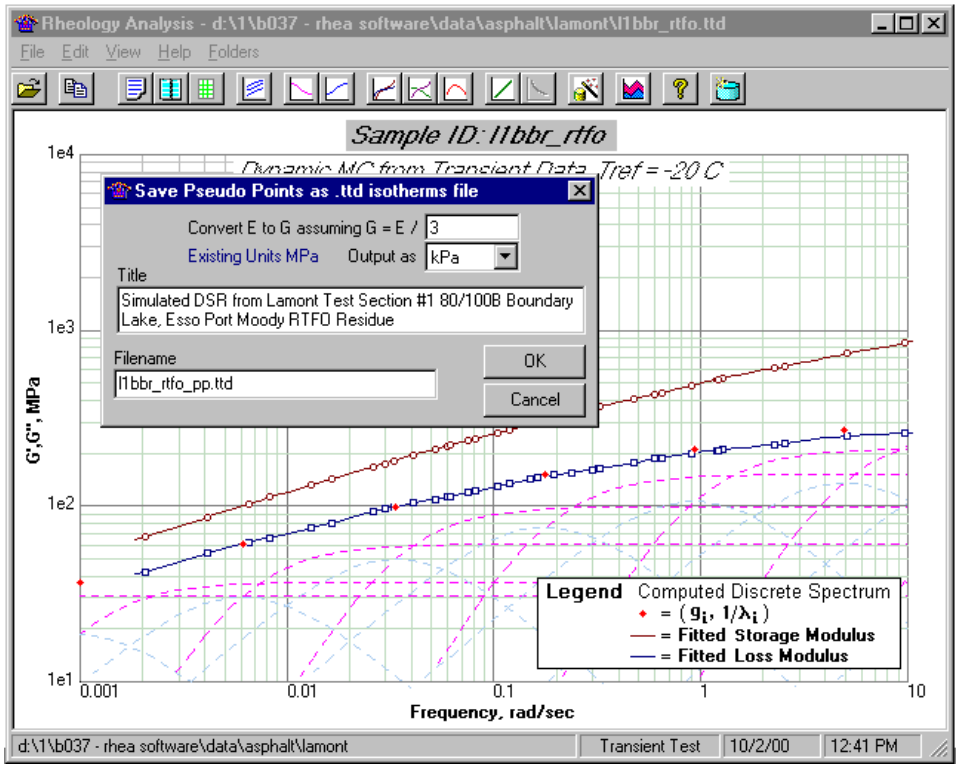


Figure 32: Saving BBR Time Domain data as a Frequency Sweep

After the data has been saved in this manner the next step is to combine the two files. This is achieved by using the file menu and selecting the two data files. The file merge windows are illustrated below for the example used.

It is important at this stage to review the material properties being used for the time-temperature shifting. In particular check the density, T_{ref} and T_{glass} information since this all effects shifting. The default information is taken as a simple average of the information in the data files.

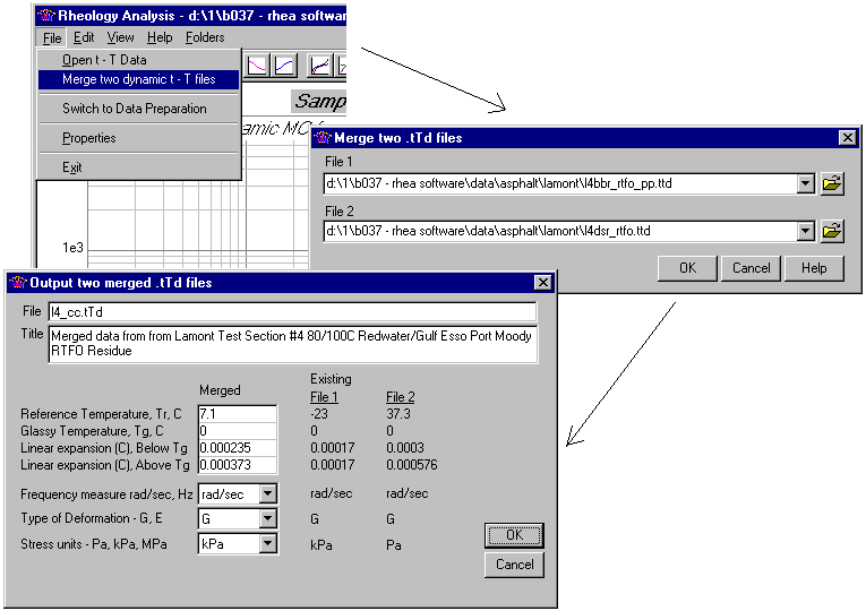


Figure 33: Steps in merging two Dynamic Data Files

Data Sets - BBR+DSR

Two data sets - combined are given in Appendix B. One of these data sets shifts automatically while the second requires some data removal to obtain the shift. The reason for this is that in these example the DSR data collected has included some spurious results as evident in the Black space plots. This data needs to be carefully inspected with the bad data removed. The data points which been excluded from the analysis are indicated by the lighter shading in the plot of G* and δ versus frequency. In the data sets these are the data items followed by a zero - see Appendix B.

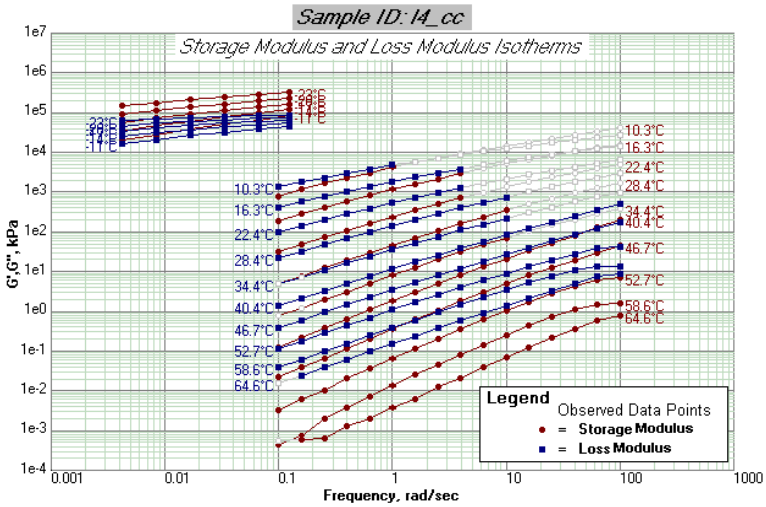


Figure 34: Lamont 4 Isotherms Illustrating DSR Data removed for shifting

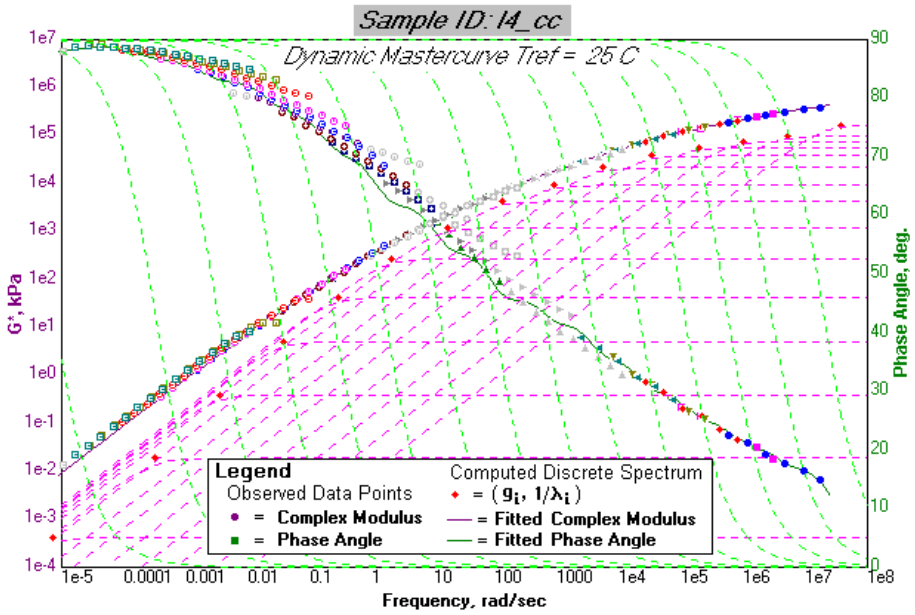


Figure 35: Lamont 4, Plot of G* and δ versus frequency - light shaded data removed

Getting Help

Abatech is dedicated to providing you with sufficient support for your software problems. All problems experienced may not be resolved immediately. However, we will endeavor to respond to user needs in a timely manner. Our web page, www.abatech.com, will contain necessary fixes and updates to programs and associated documentation as development of the product progresses. Also, you can contact us by e-mail, phone and fax at the following:

E-mail	growe@abetech.com
Fax	(772) 679-2464
Phone	(215) 258-3640

We ask that you adequately document any problem that you experience so that our development team has a complete understanding of the nature of the problem to assist with a quick resolution.

Appendix A - Data Files from Manufactures Equipment Output

Introduction

When starting the software in file reader mode the user may or may not set data files depending upon the default data file type selected in the "Data Format" dialog box. Different file extensions are used to denote differing test equipment and data format. RHEA can read data formats automatically from many equipments provided they are saved in the correct formats. We will be developing other formats as example data becomes available. Current formats are as follows:

Manufacture	Extension	Notes
Malvern (formally Bohlin)	*.d?w	Several file formats as discussed below.
Interlaken	*.ion	
Alpha-Technologies	*.rpa	Data output from RPA 2000 device.
TA Rheology	*.prn	Dynamic data which must be output using a predefined format.
IPC Asphalt Performance Tester (formally known as the simple performance tester)	*.csv	Dynamic data from IPC device saved in comma separated ASCII file format.

The selection of the file format is made via the dialog box as shown in Figure A 1.

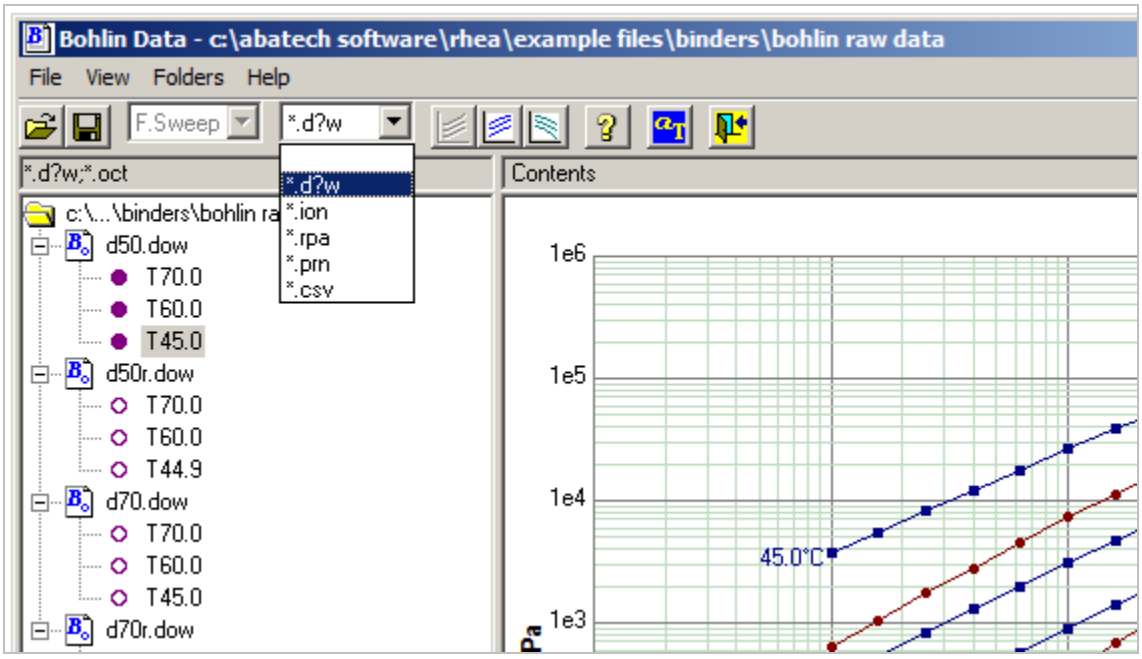


Figure A 1: Selection of data format

Bohlin (also Malvern) Files

These are the standard format data files produced by Bohlin Instruments with their rheometers. When the software is started the user can use the browse facility to locate a directory containing the D?W files.

The **RHEA™** software file reader can automatically read and view Bohlin data files - for example DOW data files. These are the standard format data files produced by Bohlin Instruments with their rheometers. When the software is started the user can use the browse facility to locate a directory containing the Bohlin data files.

Note: It is a requirement that all the files for a time-temperature superposition analysis are placed in a single directory, e.g., c:\program files\data\my material\.

Data files may be of the following type:

DCW (Data Creep Windows)

DCW Bohlin creep files

DOW (Bohlin Oscillation Windows)

Sweep Type 0. Single frequency - ***no analysis currently possible*** - *can be used for temperature sweep at single frequency - or other experimentation.*

Sweep Type 1. Table of frequencies - frequency sweep used for master analysis.

Sweep Type 2. Ramp mode- ***no analysis currently possible*** - *typically used for amplitude sweep.*

DVW (Data Viscometry Windows)

Viscometry data files - ***no analysis currently possible***.

When the user has selected (using the Folders browse feature) the directory that contains the data files the windows should be similar to that shown below. The example shown illustrates various data files. The tree as shown can be expanded or collapsed by clicking the ⊞ and ⊟ symbols adjacent to the tree.

A pull-down menu allows the user to select either ***frequency sweep*** (F.Sweep) or ***creep*** data files for analysis.

The graph buttons on the Toolbar are activated for the type of data selected at this level.

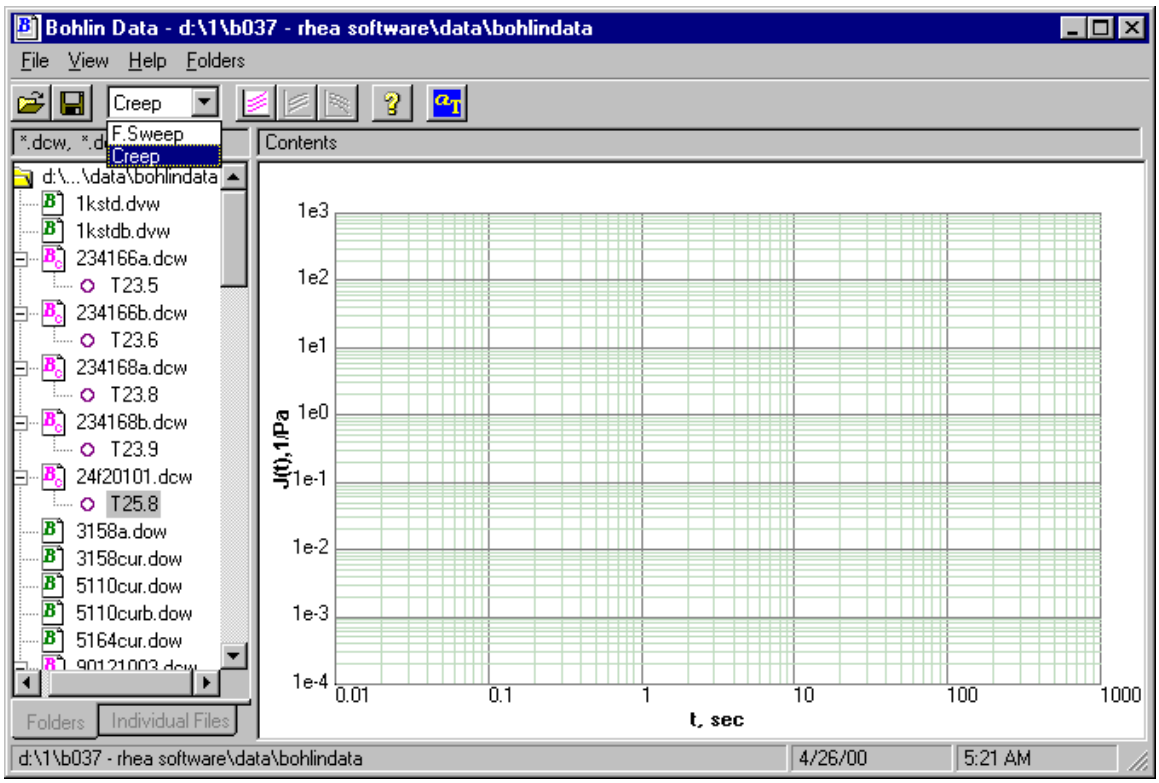


Figure A 2: The RHEA™ file reading system

For dynamic data the user has two choices for display, G' and G" or G* and sinδ whereas for creep data the compliance J(t) is displayed.

A single file may contain many isotherms or just a single isotherm. Either right clicking with the mouse on the individual isotherm or the file name can select the isotherms. The drop down menu has the file choice deactivated if the right click is performed on the isotherm. The displayed menu is different for this feature if the right click is performed on the "file" or the "isotherm." The example shown below is that displayed when activating the menu of a file line which then allows the user to select all isotherms of all files. If this is displayed on a isotherm the equivalent line allows the user to select all isotherms of that single file.

In addition to selection of isotherms the user can view the file information in a text box, Figure A 4, and the table of isotherms, Figure A 5. This functionality is useful for assigning file names and viewing information from within the **RHEA™** software.

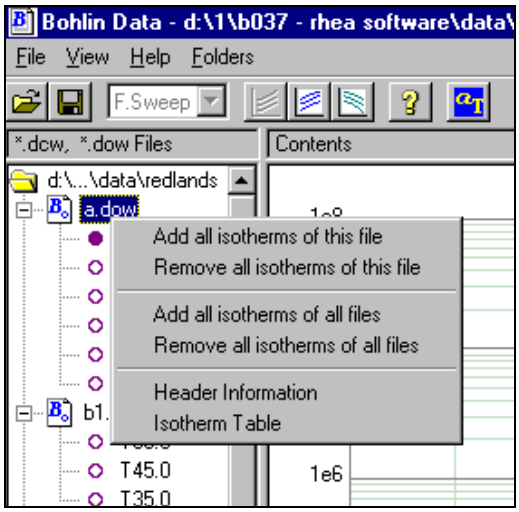


Figure A 3: Adding and removing isotherms

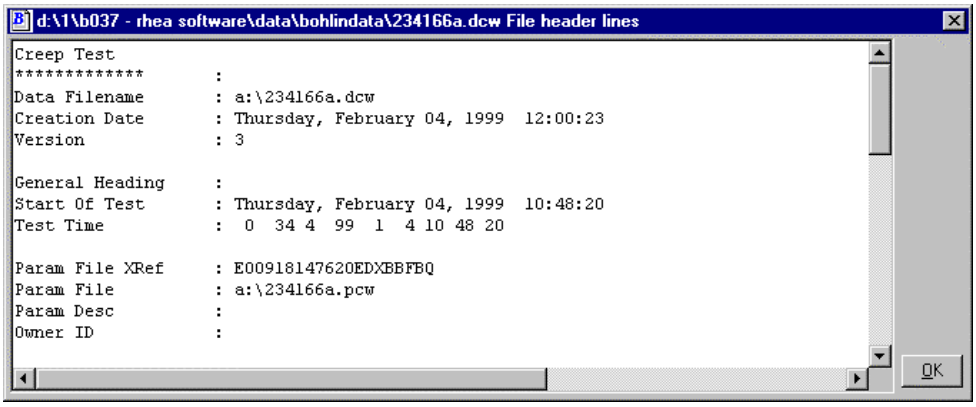
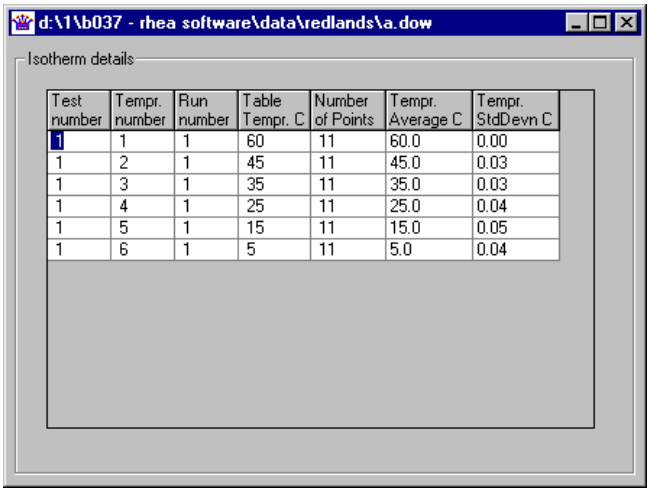


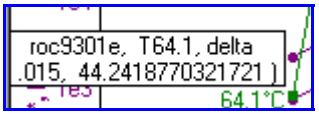
Figure A 4: File information



Test number	Tempr. number	Run number	Table Tempr. C	Number of Points	Tempr. Average C	Tempr. StdDevn C
1	1	1	60	11	60.0	0.00
1	2	1	45	11	45.0	0.03
1	3	1	35	11	35.0	0.03
1	4	1	25	11	25.0	0.04
1	5	1	15	11	15.0	0.05
1	6	1	5	11	5.0	0.04

Figure A 5: Isotherm Table

As the mouse is located over a data point, the information on the data point is displayed.



Information displayed shows; filename, temperature, data type, frequency and value.

Figure A 6: Data point information

Many times in data collection it is desirable to remove data points from the analysis. The software uses the DOW files to create a "***.ttd**" run file. The user can elect to remove points from the run file by using facility provided with the graphical user interface. The data point can be removed from the analysis by a right mouse click and then selecting remove. The removed data point is still visible but as open data point. Repeating the same steps the data point can be reinserted into the analysis.

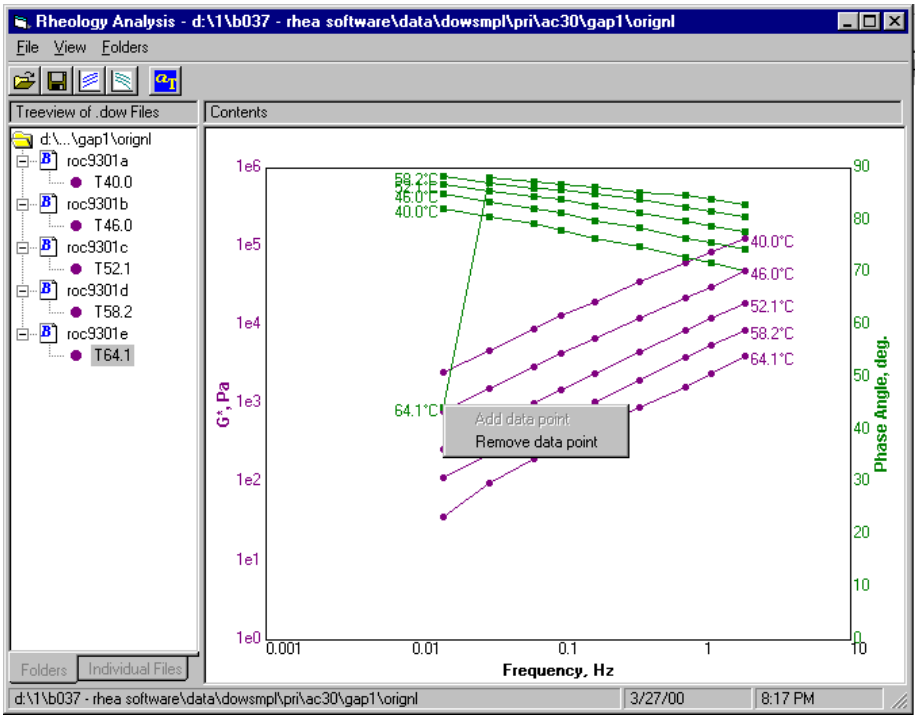


Figure A 7: Removal of a data point

Interlaken Files

Interlaken manufactures a shear-testing device that produces visco-elastic material properties for large cylindrical samples of asphalt material (typically 150mm diameter by 50mm height). These devices are in routine use by research institutions and test laboratories in North America. The software requires that the *.dat[2] extension is replaced by a *.ion extension so that the file is recognized as an Interlaken data file. The

[2] A *.dat is a very common file extension. So that the software compares a limited number of file types we have adopted a file naming convention for data files being read and have used a *.ion to represent the Interlaken file type.

icon  is used to represent an Interlaken file. When the user selects the Interlaken option for raw data files the window appears as illustrated below:

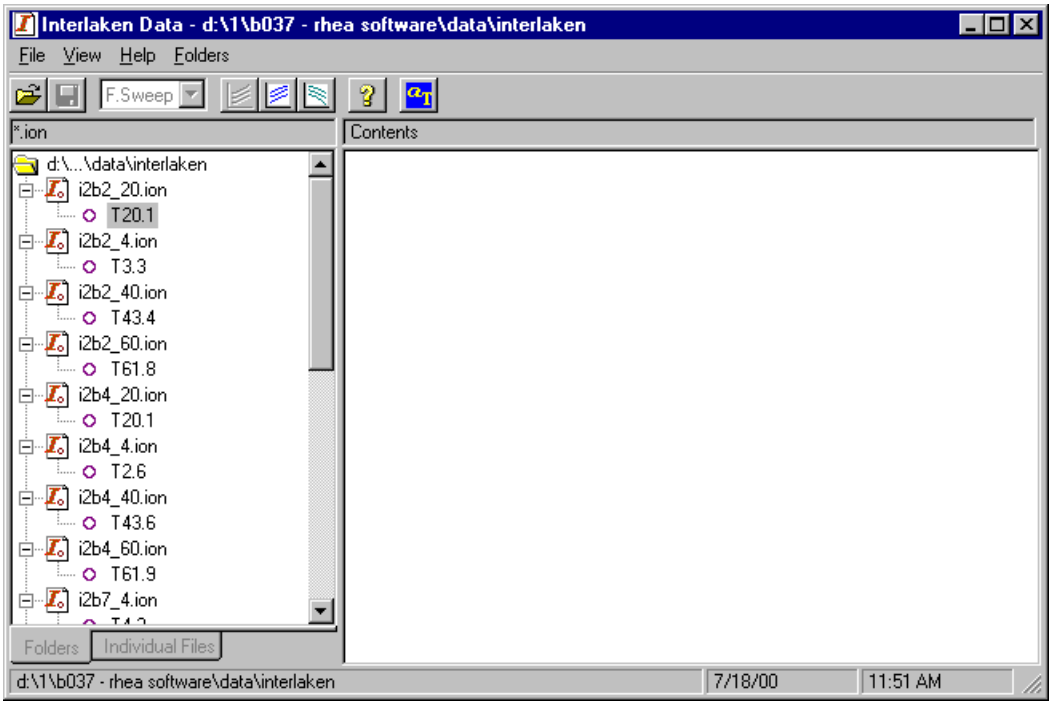


Figure A 8: The Interlaken data files

The user selects the data files as in the manner previously described for Bohlin files. Isotherms may be selected and individual data points may be excluded from the data sets. The objective of this process is to produce a run file in the format described in the next section. A typical data file from the Interlaken device is illustrated below. Files of other formats from the test device may need conversion via a text editor to ensure that the software can read them.

```
Frequency Test Data of 05-31-2001
ABCDED
ABC SAMPLES
Shear G.L.=   1.97 in
Radius   2.95
Temperature=  40.0 C
Test Temperature=  43.6 C


START_OF_DATA
Frequency     Period    Stress    Strain        G*     Delta        G'       G''
   Hz                      PSI     IN/IN       PSI   Degrees      PSI       PSI
10.00      100            3.52  0.000125     28206     59.56     14292     24317
 5.00      100            2.09  0.000102     20530     59.15     10526     17626
 2.00       20            1.18  0.000094     12635     62.13      5906     11169
 1.00       20            0.83  0.000093      8969     58.72      4656      7666
 0.50       10            0.56  0.000095      5904     56.51      3258      4924
 0.20       10            0.34  0.000091      3686     50.93      2323      2861
 0.10        7            0.24  0.000094      2543     47.81      1708      1884
 0.05        4            0.14  0.000096      1485     48.44       985      1111
 0.02        4            0.17  0.000095      1810     20.66      1694       639
 0.01        4            0.12  0.000093      1269     27.31      1127       582
```

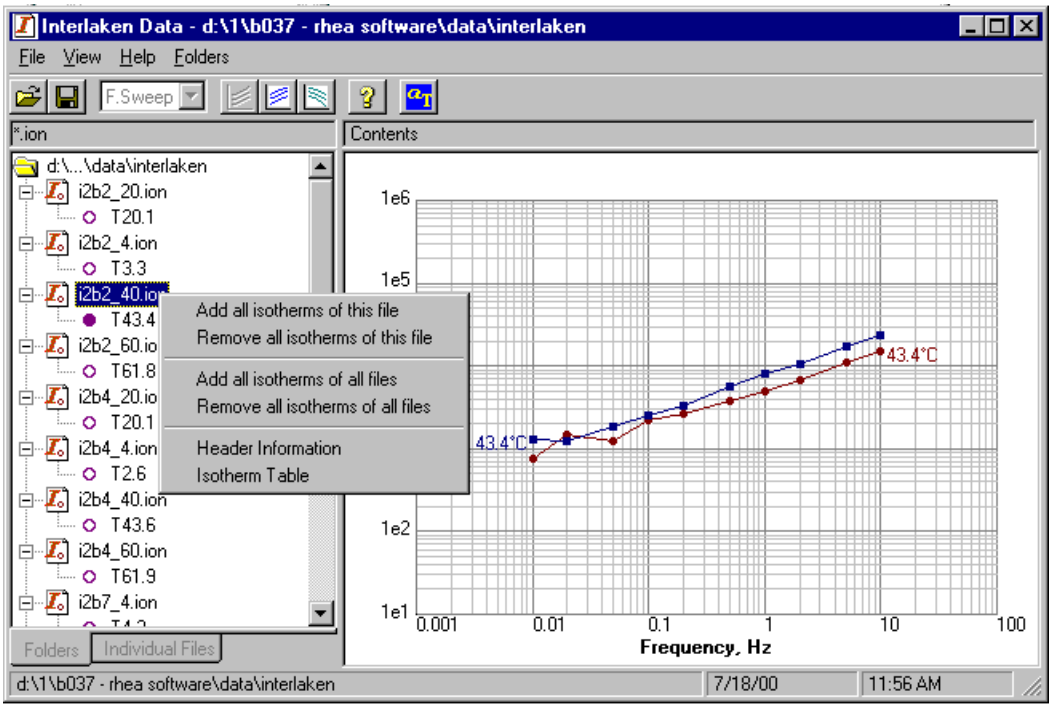


Figure A 9: Isotherm selected

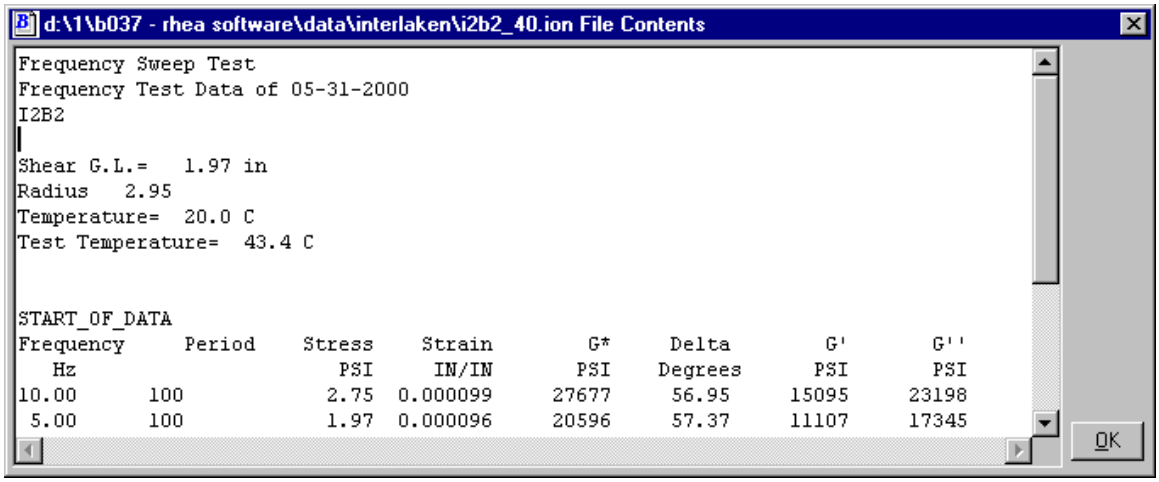


Figure A 10: File information window

Alpha-Technologies

The data format was developed for use with the RPA 2000 developed by Alpha Technologies LLC (see - http://www.alpha-technologies.com/instruments/rpa.htm?rheo). The format used is an ASCII file as shown in Figure A 11.

RPA 2000

Test Type hgb
Test Name JF Matrix 75 d FKM
Test Time 14.47.45
Test Date 27-06-03
User Name henri

Die Type Biconical Die
Die Gap 0.487

Project JF
Product FKM
Sample number Sample 3
Batch 01
Remarks Dartek

Subtest 0 READY

Temp 75.0 °C

Subtest 1 TIMED

Time 3.00 m.m
Temp 75.0 °C
Freq 10.00 rad/s
Strain 0.56 %

Min S' dNm 0.263
Max S' dNm 0.275
Min S" dNm 0.102
Max S" dNm 0.117
S" @ Min S' dNm 0.106
S" @ Max S' dNm 0.108

Subtest 2 MATRIX

Temperature	Frequency	Strain	S'	S"	S*	G'	G"	G*	n'	Tan Delta	UTemp	LTemp
°C	rad/s	%	dNm	dNm	dNm	kPa	kPa	kPa	Pa-s		°C	°C		
75.0	200.00	5.02	4.512	1.147	4.655	491.62	125.02	507.27	2536.3	0.254	75.0	75.1		
75.0	98.59	5.02	4.040	1.102	4.188	440.23	120.1	456.31	4628.4	0.273	75.0	74.9		
75.0	48.60	5.02	3.541	1.111	3.712	384.76	120.72	403.26	8297.6	0.314	75.0	74.8		
75.0	23.95	5.02	3.044	1.085	3.231	331.67	118.18	352.09	14701	0.356	75.0	74.9		
75.0	11.81	10.04	5.056	2.077	5.466	274.69	112.84	296.97	25145	0.411	75.0	75.0		
75.0	5.82	10.04	4.136	1.949	4.573	224.1	105.57	247.72	42561	0.471	75.0	75.0		
75.0	2.87	10.04	3.289	1.773	3.736	178.44	96.19	202.72	70624	0.539	75.0	75.0		
75.0	1.41	10.04	2.542	1.547	2.976	137.9	83.954	161.45	1.1454E+005		0.609	75.0	75.0	
75.0	0.70	19.95	3.751	2.581	4.553	102.32	70.406	124.2	1.7755E+005		0.688	75.0	75.0	
75.0	0.34	19.95	2.759	2.094	3.463	75.248	57.111	94.467	2.7757E+005		0.759	75.0	75.0	
75.0	0.17	19.95	1.991	1.632	2.574	54.341	44.543	70.264	4.1418E+005		0.820	75.0	75.0	
75.0	0.08	19.95	1.448	1.253	1.915	39.538	34.211	52.284	6.5694E+005		0.865	75.0	75.0	
75.0	0.04	19.95	1.043	0.941	1.405	28.482	25.698	38.362	9.6402E+005		0.902	75.0	75.0	
75.0	0.02	19.95	0.753	0.699	1.028	20.544	19.073	28.033	1.4089E+006		0.928	75.0	75.0	
75.0	0.01	19.95	0.535	0.515	0.742	14.616	14.054	20.276	1.9362E+006		0.962	75.0	75.0	

Figure A 11: Data format required for RPA 2000 machine

IPC Asphalt Performance Tester

The data for this type of test is presented in Figure A 12 and consists of a comma separated file format.

```
Test Information
**********
Project name,Polymer Comparison
Operator name,KXP
Target test temperature,50
Target confining stress,0
Average dynamic strain range from 75 to 125 micro-strain
Contact stress,5
Initial modulus,116.03
Axial gauge length,2.76
Comments
Specimen Information
**********
Identification,PC-10 11

 Dimensions,Point 1,Point 2,Point 3,Point 4,Point 5,Point 6,Average,Std Dev.
 Diameter (in),3.740,,,,,, 3.740,
 Height (in),5.906,,,,,, 5.906,

Cross-sectional area (in²), 10.987

Conditioning time,

Comments/Properties
*********
Test date and time,Mon, May 14, 2007, 10:50 AM
Test results summary
,25 Hz,20 Hz,10 Hz,5 Hz,2 Hz,1 Hz,0.5 Hz,0.2 Hz,0.1 Hz,0.01 Hz
 Dynamic modulus (ksi),2137,2060,1864,1669,1415,1236,1059,852.0,717.3,383.4
 Phase angle (Degrees),13.09,13.41,14.80,16.31,18.37,20.04,21.65,24.05,25.47,29.41
 Average temperature  (°F),50.3,50.3,50.3,50.3,50.3,50.2,50.2,50.2,50.3,50.2
 Average confining pressure  (psi),0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2
 Average micro-strain,42,45,52,60,72,82,90,96,96,93
 Load drift (%),3.7,3.4,2.6,4.0,2.6,0.7,0.0,0.0,0.0,0.0
 Load standard error (%),27.0,22.1,21.3,17.3,12.0,6.0,2.1,0.7,0.2,0.4
 Average deformation drift (%),-131.7,-110.2,-119.8,-129.7,-138.8,-133.5,-127.4,-122.7,-117.2,-100.1
 Average deformation standard error (%),24.8,20.1,19.3,15.5,11.2,5.7,3.0,2.0,2.3,2.9
 Deformation uniformity (%),22.4,21.9,22.1,21.3,19.8,19.3,19.0,19.0,18.4,18.1
 Phase uniformity (Degrees),0.6,0.6,0.6,0.8,0.8,0.7,0.7,0.7,0.8,0.9

```

Figure A 12: Data format for IPC CSV files - view using the facility within RHEA

Run File Creation

After the user has selected the isotherms required for the analysis the file button  is used to create a run file. The run file is in ASCII format and is described in the next section of this manual. The user is prompted for additional information, as illustrated below:

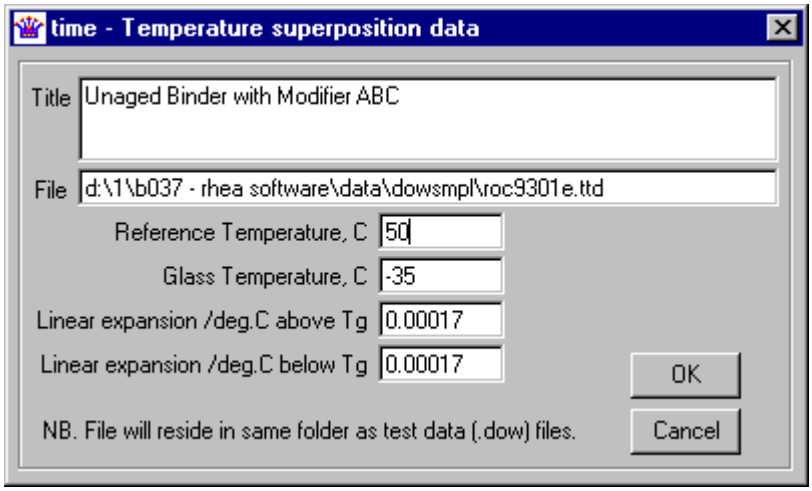


Figure A 13: Data file information

The information requested is as follows:

1. Title - this information will appear on the title area in the advanced graphing options.
2. File - the run file which is created has the name ***.tdd**. This file will be located in the directory in which the **raw-data** files were obtained from. The user may wish to make changes to the file name so that multiple analysis may be conducted with the same base data but with different isotherms/data points included or excluded.
3. Reference Temperature - the reference temperature to which all master curves and visco-elastic functions will be obtained. This temperature must lie within the range of temperatures covered by the isotherms.
4. Glass Temperature - The glass transition temperature (Tg) is used to define different coefficients of linear expansion throughout the temperature range. In some materials research work has shown that it is appropriate to use different values either side of this point.
5. Linear expansion/deg.C above Tg - The linear expansion coefficient above the glass transition temperature.
6. Linear expansion/deg.C below Tg - The linear expansion coefficient below the glass transition temperature.

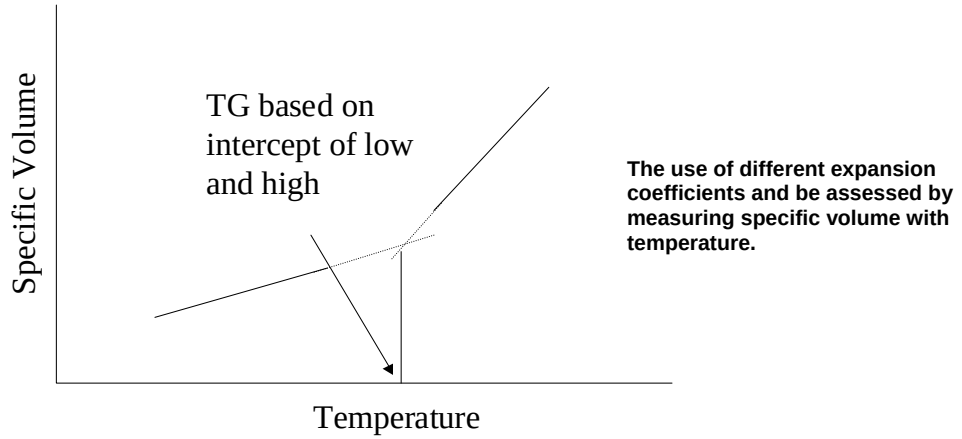


Figure A 14: Variation in expansion coefficients measured by specific volume

The expansion coefficient are used with a density term to provide a vertical shift to the data which is consistent with the change in density of the material (Ferry, 1980). If the user does not wish to use this correction then an arbitrary value may be chosen for the T_g and 0 is used for the expansion values.

Appendix B - Combined BBR-DSR Data Sets

```
Merged data from from Lamont Test Section #1 80/100B Boundary Lake, Esso Port Moody RTFO
Residue
L 16  25  0 1 1 .00017 .00025 1.02 0 r G kPa
-30.0 6 1
 -2.3802112e+00  5.0706846e+00  4.7194749e+00 1
 -2.0791812e+00  5.1513702e+00  4.7803760e+00 1
 -1.7781512e+00  5.2336622e+00  4.8268598e+00 1
 -1.4771213e+00  5.3039569e+00  4.8643724e+00 1
 -1.1760913e+00  5.3744010e+00  4.9056170e+00 1
 -9.0308999e-01  5.4320321e+00  4.9204397e+00 1
-27.0 6 1
 -2.3802112e+00  4.8840905e+00  4.5872491e+00 1
 -2.0791812e+00  4.9773897e+00  4.6650567e+00 1
 -1.7781512e+00  5.0683230e+00  4.7199362e+00 1
 -1.4771213e+00  5.1489117e+00  4.7797163e+00 1
 -1.1760913e+00  5.2317351e+00  4.8289783e+00 1
 -9.0308999e-01  5.2965431e+00  4.8610496e+00 1
-25.0 6 1
 -2.3802112e+00  4.8043646e+00  4.5310782e+00 1
 -2.0791812e+00  4.8979054e+00  4.5995341e+00 1
 -1.7781512e+00  4.9919948e+00  4.6762119e+00 1
 -1.4771213e+00  5.0812230e+00  4.7292692e+00 1
 -1.1760913e+00  5.1619649e+00  4.7904293e+00 1
 -9.0308999e-01  5.2369166e+00  4.8331211e+00 1
-24.0 6 1
 -2.3802112e+00  4.7586786e+00  4.5000323e+00 1
 -2.0791812e+00  4.8590096e+00  4.5685170e+00 1
 -1.7781512e+00  4.9503350e+00  4.6452757e+00 1
 -1.4771213e+00  5.0448396e+00  4.7085711e+00 1
 -1.1760913e+00  5.1267942e+00  4.7631443e+00 1
 -9.0308999e-01  5.2020983e+00  4.8172178e+00 1
-21.0 6 1
 -2.3802112e+00  4.5352786e+00  4.3157236e+00 1
 -2.0791812e+00  4.6402052e+00  4.3955248e+00 1
 -1.7781512e+00  4.7423332e+00  4.4883833e+00 1
 -1.4771213e+00  4.8455539e+00  4.5604705e+00 1
 -1.1760913e+00  4.9366767e+00  4.6343788e+00 1
 -9.0308999e-01  5.0232655e+00  4.6983935e+00 1
-18.0 6 1
 -2.3802112e+00  4.3552492e+00  4.1522516e+00 1
 -2.0791812e+00  4.4625868e+00  4.2572807e+00 1
 -1.7781512e+00  4.5775592e+00  4.3472580e+00 1
 -1.4771213e+00  4.6781339e+00  4.4310210e+00 1
 -1.1760913e+00  4.7832699e+00  4.5206030e+00 1
 -9.0308999e-01  4.8729315e+00  4.5814009e+00 1
10.0 16 1
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 -7.9997073e-01  2.8034571e+00  2.8536982e+00 1
 -5.9998036e-01  2.9216865e+00  2.9489018e+00 1
 -4.0000782e-01  3.0293838e+00  3.0453230e+00 1
 -1.9997064e-01  3.1367206e+00  3.1335389e+00 1
  0.0000000e+00  3.2430380e+00  3.2253093e+00 1
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  4.0001964e-01  3.4440448e+00  3.3979400e+00 1
  5.9999218e-01  3.5403295e+00  3.4828736e+00 1
  8.0002936e-01  3.6344773e+00  3.5622929e+00 1
  1.0000000e+00  3.7267272e+00  3.6434527e+00 1
  1.2000293e+00  3.8162413e+00  3.7218106e+00 1
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  1.5999922e+00  3.9894498e+00  3.8744818e+00 1
  1.8000294e+00  4.0755470e+00  3.9508515e+00 1
  2.0000000e+00  4.1583625e+00  4.0211893e+00 1
16.0 16 1
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 -7.9997073e-01  2.3117539e+00  2.4361626e+00 1
 -5.9998036e-01  2.4409091e+00  2.5477747e+00 1
 -4.0000782e-01  2.5634811e+00  2.6522463e+00 1
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22.4 16 1
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 -7.9997073e-01  1.7604225e+00  1.9726656e+00 1
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  1.4000196e+00  1.7888751e+00  2.0530784e+00 1
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  1.8000294e+00  2.0681859e+00  2.3053514e+00 1
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 -5.9998036e-01 -5.4363400e-01  1.5228830e-01 1
 -4.0000782e-01 -3.2422170e-01  3.2221930e-01 1
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  4.0001964e-01  4.8287360e-01  9.6378780e-01 1
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64.6 16 1
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  2.0000000e+00  2.2010810e-01  8.6510400e-01 1
```

```
Merged data from from Lamont Test Section #4 80/100C Redwater/Gulf Esso Port Moody RTFO
Residue
L 15  25  0 1 1 .00017 .00017 1.02 0 r G kPa
-23.0 6 1
 -2.3802112e+00  5.1766222e+00  4.7929685e+00 1
 -2.0791812e+00  5.2517202e+00  4.8407009e+00 1
 -1.7781513e+00  5.3271204e+00  4.8711215e+00 1
 -1.4771213e+00  5.3891403e+00  4.8933738e+00 1
 -1.1760913e+00  5.4509417e+00  4.9240410e+00 1
 -9.0308999e-01  5.5015385e+00  4.9267395e+00 1
-20.0 6 1
 -2.3802112e+00  4.9541163e+00  4.6655393e+00 1
 -2.0791812e+00  5.0462148e+00  4.7310729e+00 1
 -1.7781513e+00  5.1394058e+00  4.7802744e+00 1
 -1.4771213e+00  5.2168179e+00  4.8187736e+00 1
 -1.1760913e+00  5.2935864e+00  4.8647898e+00 1
 -9.0308999e-01  5.3569567e+00  4.8819528e+00 1
-17.0 6 1
 -2.3802112e+00  4.7451904e+00  4.5341941e+00 1
 -2.0791812e+00  4.8600107e+00  4.6176020e+00 1
 -1.7781513e+00  4.9635996e+00  4.6732101e+00 1
 -1.4771213e+00  5.0558145e+00  4.7392427e+00 1
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 -9.0308999e-01  5.2184736e+00  4.8215064e+00 1
-14.0 6 1
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 -9.0308999e-01  4.9150777e+00  4.6515706e+00 1
10.3 16 0
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 -7.9997073e-01  3.0681859e+00  3.2552725e+00 1
 -5.9998036e-01  3.2174839e+00  3.3673559e+00 1
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  4.0001964e-01  3.8555192e+00  3.8585372e+00 0
  5.9999218e-01  3.9652017e+00  3.9420081e+00 0
  8.0002936e-01  4.0681859e+00  4.0211893e+00 0
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  1.8000294e+00  4.5289167e+00  4.3654880e+00 0
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16.3 16 1
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  1.5999922e+00  4.0211893e+00  4.0253059e+00 0
  1.8000294e+00  4.1172713e+00  4.1038037e+00 0
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22.4 16 1
```

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  1.2000293e+00  3.2552725e+00  3.4456042e+00 0
  1.4000196e+00  3.3747483e+00  3.5477747e+00 0
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28.4 16 1
 -1.0000000e+00  6.8214510e-01  1.3384565e+00 1
 -7.9997073e-01  8.8309340e-01  1.5118834e+00 1
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  1.8000294e+00  3.1172713e+00  3.3617278e+00 0
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34.4 16 1
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 -7.9997073e-01  8.9905100e-02  8.6332290e-01 0
 -5.9998036e-01  2.9225610e-01  1.0492180e+00 1
 -4.0000782e-01  4.8572140e-01  1.2174839e+00 1
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