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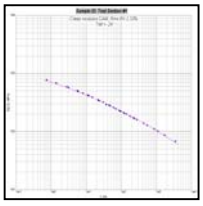
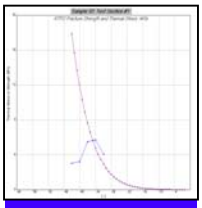
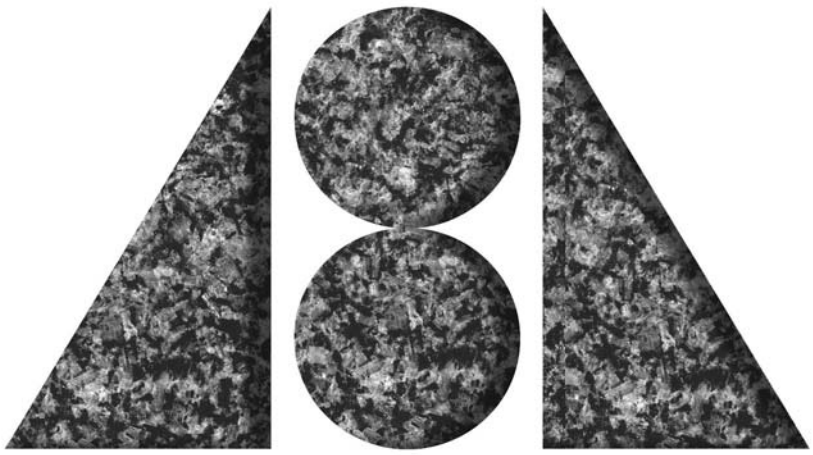


Thermal Stress Analysis Routine Software Users Manual



TSAR™



-Important Notice-

You have been provided with a software security dongle, which enables you to use the TSAR™, TSAR Plus™ or TSAR Plus™ 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.

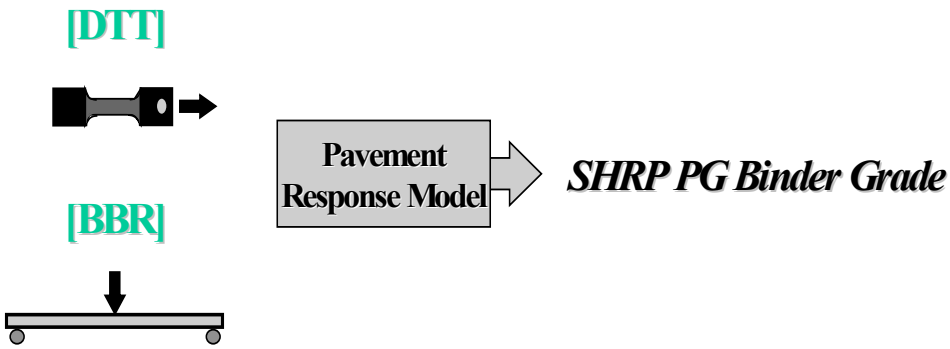
Please make sure that you connect the dongle to your parallel port before running the software.

-CONTENTS-

Introduction

Thank you for obtaining a copy of the TSAR™ software. The **TSAR™** software is a rapid user-friendly method to determine the ***SHRP binder grade***. **TSAR™** determines the critical temperature that corresponds to thermal cracking based upon Bending Beam Rheometer (BBR) and Direct Tension Testing (DTT) for the proposed new AASHTO binder specification.

The BBR and DTT methods were developed as part of SHRP. Recently, the low temperature requirements have been refined to predict at which temperature a binder fails in single event thermal cracking. This temperature will replace the stiffness, m-value and failure strain.



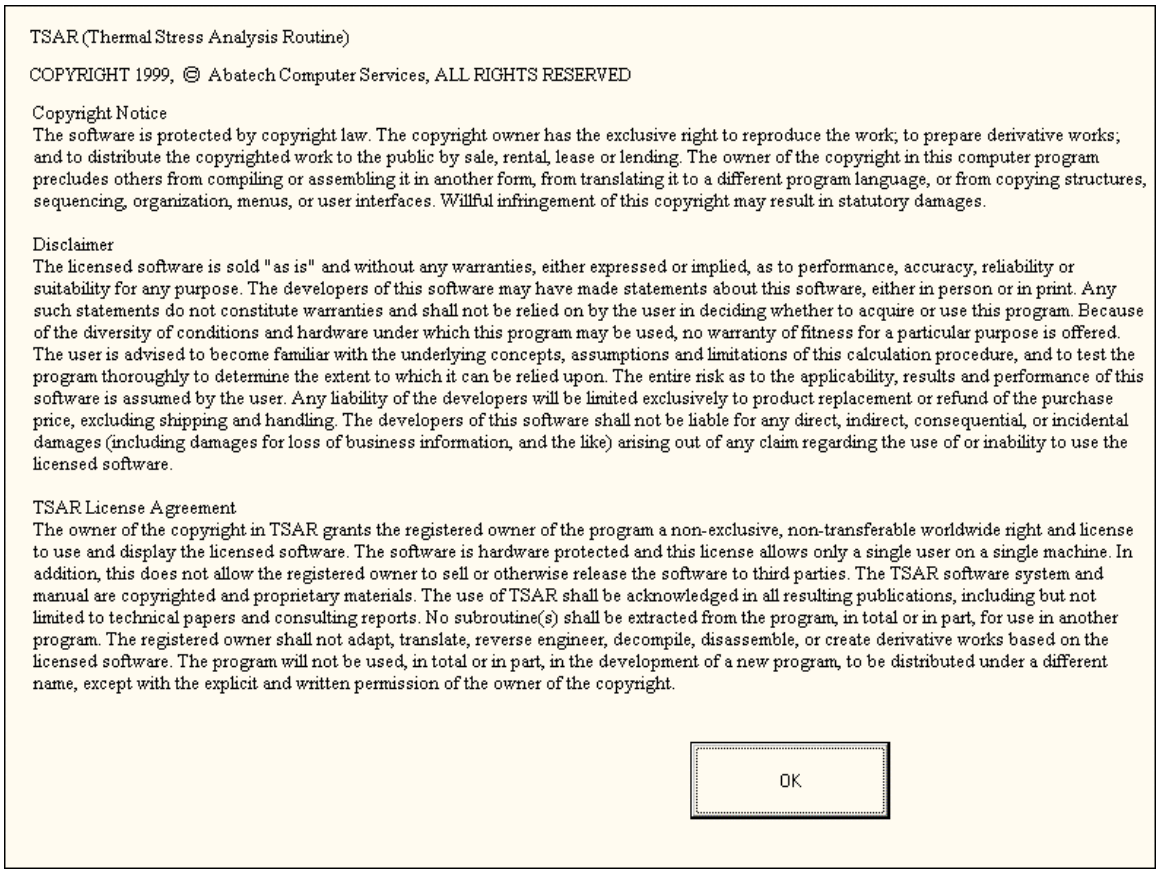
For asphalt producers, agencies and test laboratories this software provides a vital tool to classify binder systems.

The data from the BBR and DTT tests are entered into a form. The BBR data is used to compute the thermal stress in the pavement using the specified cooling rate and other material parameters such as the coefficient of linear expansion. Next, a plot of stress versus temperature is then developed. The DTT test data is compared to the induced stress and the critical cracking temperature determined. Alternatively, a pass/fail criterion is applied to certify if a binder meets a specific ***SHRP binder grade*** at the temperatures evaluated.

This manual provides a functional explanation of the programs working and does not explain the background research. References to background information may be found on the web site www.abatech.com.

Agreement

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

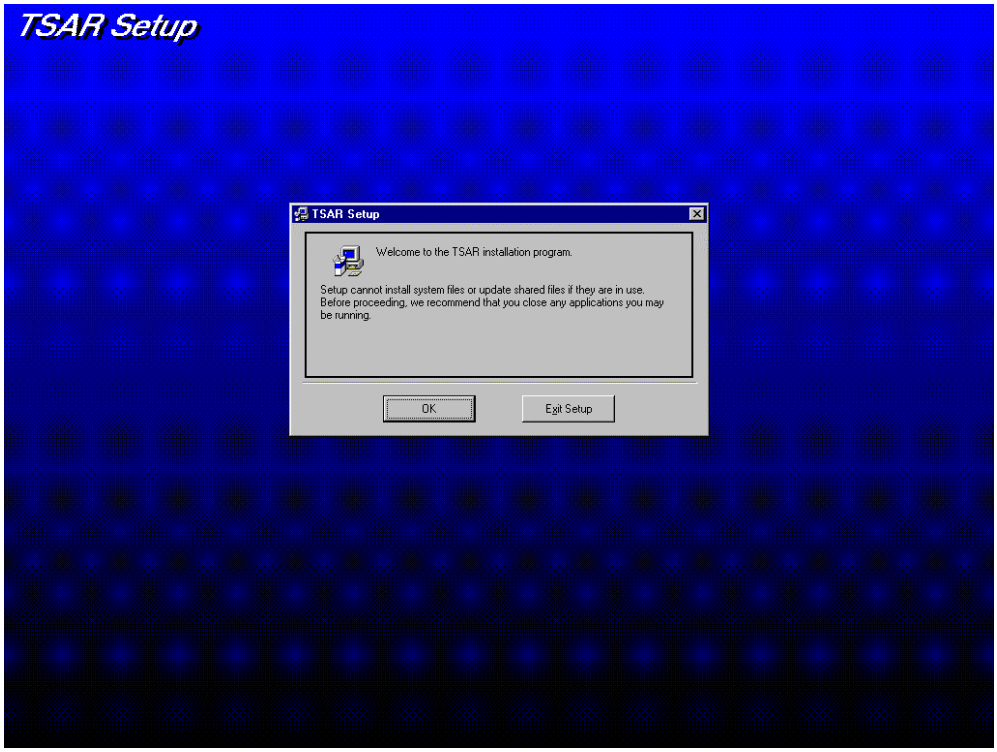


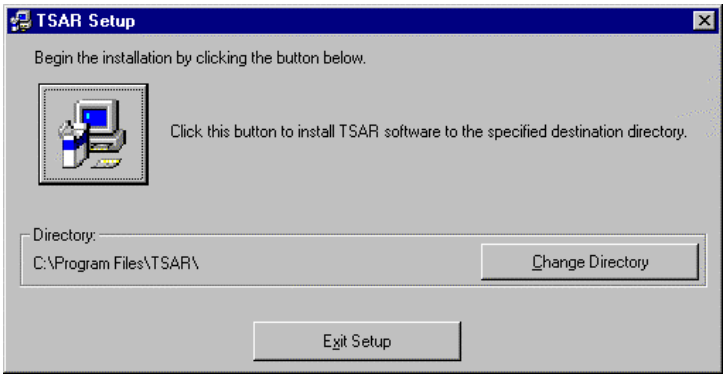
Setup

The setup operation is similar for TSAR™ and TSAR Plus™ with the exception of the disks. Both versions of the software are protected to avoid unauthorized distribution, to protect against software theft, and to licensed to a single machine and single user, with a hardware protection device (dongle) which enables only one user to work with the software at any one time. The set procedure is described in detail below.

Installing the Software

Run ***setup.exe*** from disk 1 of the supplied disks. The setup program then ask a few simple questions relating to the location on the computer that you wish to install the files to. **TSAR™** and **TSAR Plus™** must be installed on a local drive rather than on a network drive.





After setup is complete you will need to install software security to enable use of the program.

Software Security

The **TSAR™** and **TSAR Plus™** Software is copy protected using Rainbow Technologies protection systems. Both programs are protected with the use of a dongle. 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 Users

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

This file " **NTDongleFix.zip**" may be downloaded from www.abatech.com or can be obtained from our technical support team (see above for contact information).

To install NT drivers for Rainbow SuperPro Dongle.

1) Login as Administrator
2) Extract files from zip to a floppy
3) Run the program setupx86.exe from floppy
4) Choose Install from menu.
5) When the program asks for path to driver type in A:\
6) Click OK.

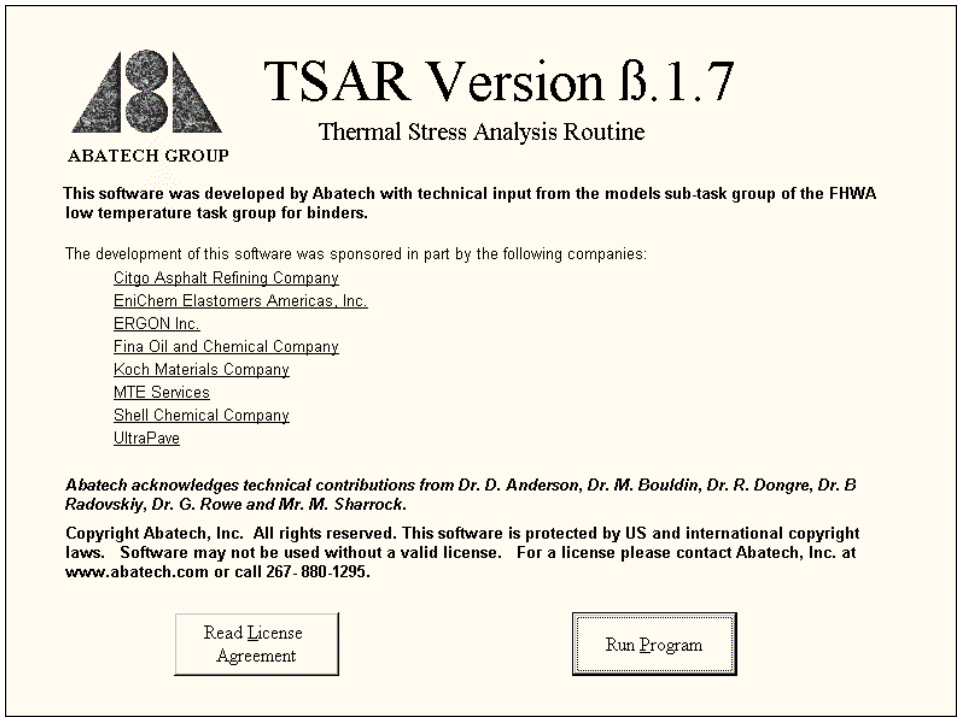
If successfully installed, 'Error 12' message will not be displayed.

The same setup program can be used to remove the drivers if desired.

Getting Started with TSAR™

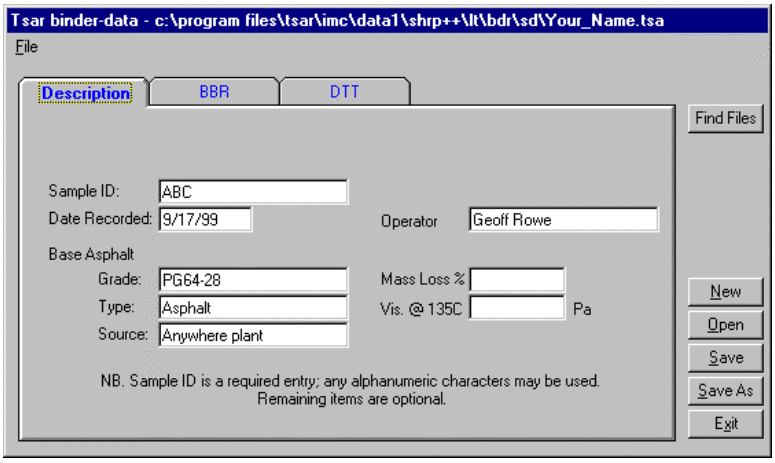
Running the Software

Launch TSAR Software. A screen will appear as illustrated. This screen acknowledges technical and industry support of various individuals and groups who have made a significant contribution to the development work of this software. The license agreement may be viewed or the program started by implementing the ***Run Program*** command.



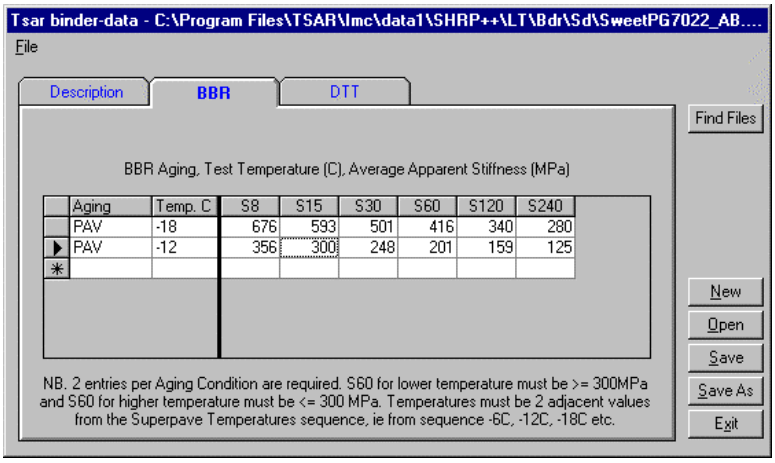
Entering Test Data

From file data select "Tsar Data" which brings up 3 "Tab" forms and enter the test data.



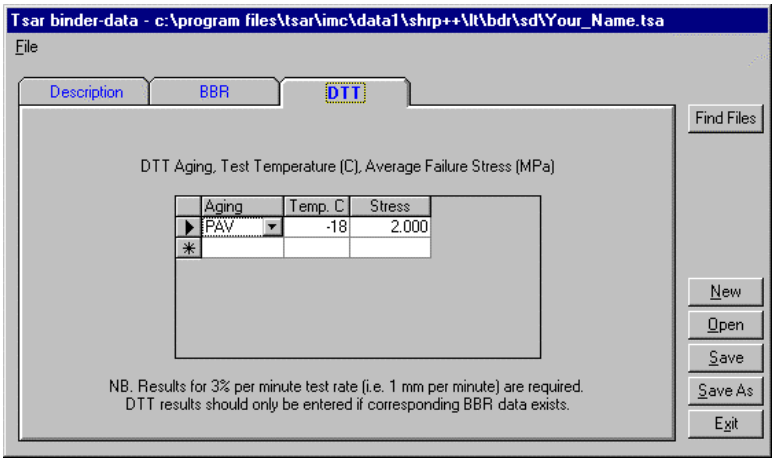
The test data is needed from both the BBR and the DT test. The user in this instance is evaluating a binder as a PGXX-28, which requires DT test data at -18°C. The input of Mass Loss and Viscosity is optional.

Two BBR isotherms are used which bracket S=300 MPa at T=60 seconds.

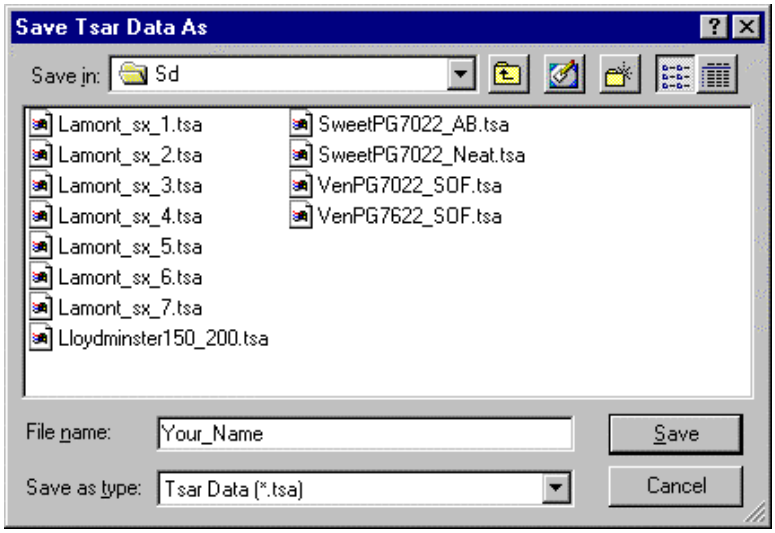


The user will generally run a BBR test at a temperature that is expected to yield a result of S60 close to 300MPa. If the measured value is ≤ 300MPa then the subsequent test(s) will be at lower temperatures. If the measured result is ≥ 300MPa then the subsequent test(s) will be at higher temperatures.

The temperatures used for the DTT test are shifted by 10°C from the specification temperature. For example when considering a -28 grade the DTT test is performed at -28+10 = -18°C. Generally, the failure stress in the DTT ranges between 1 and 5 MPa.

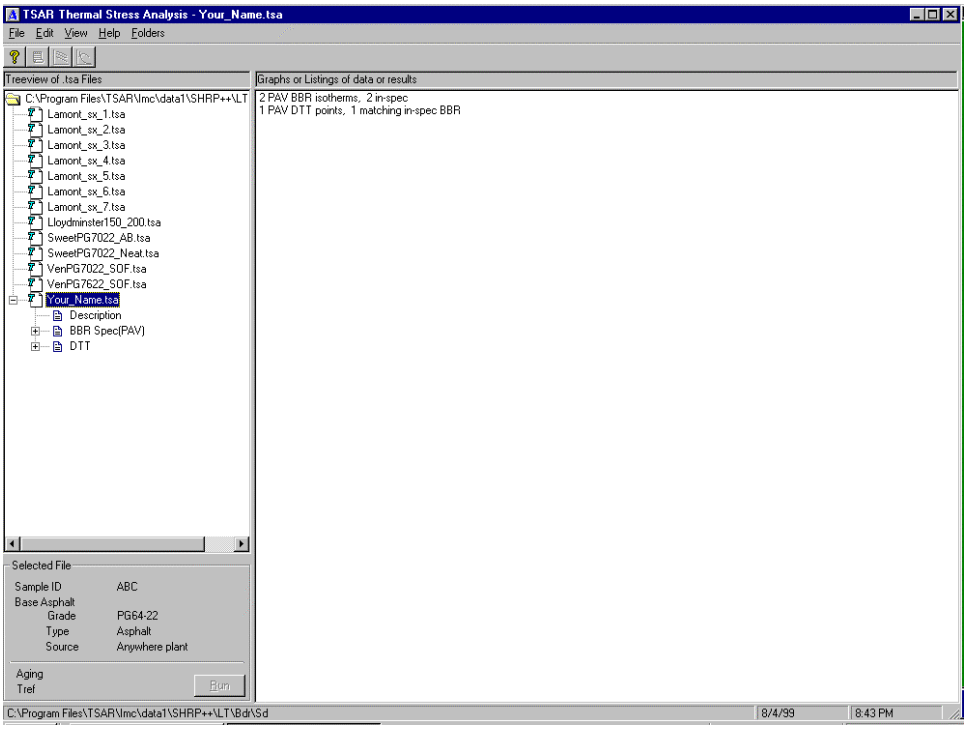


Save file as ***your_name.tsa***

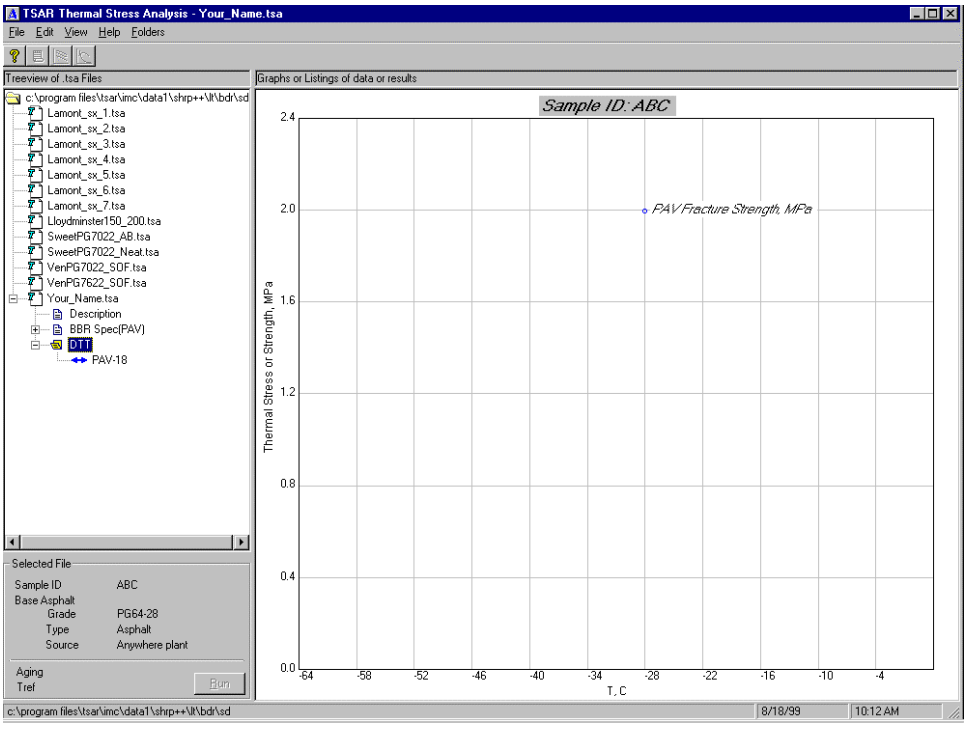


Running the Analysis

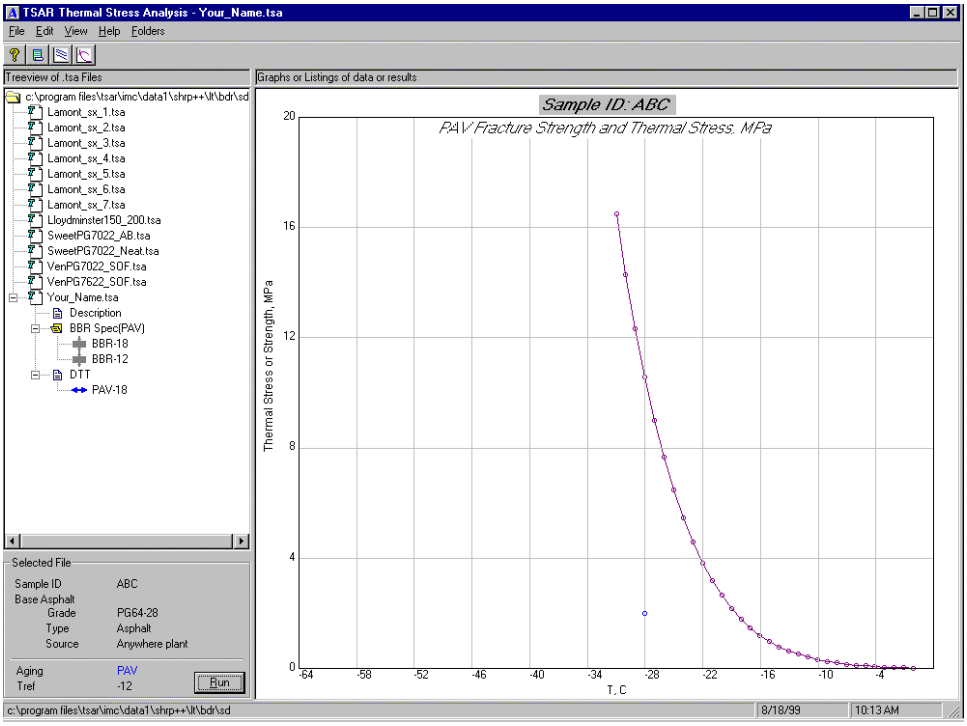
Select file from the list of files. Note at this stage you may need to use the "browse menu" depending where you saved the file on the hard disk.



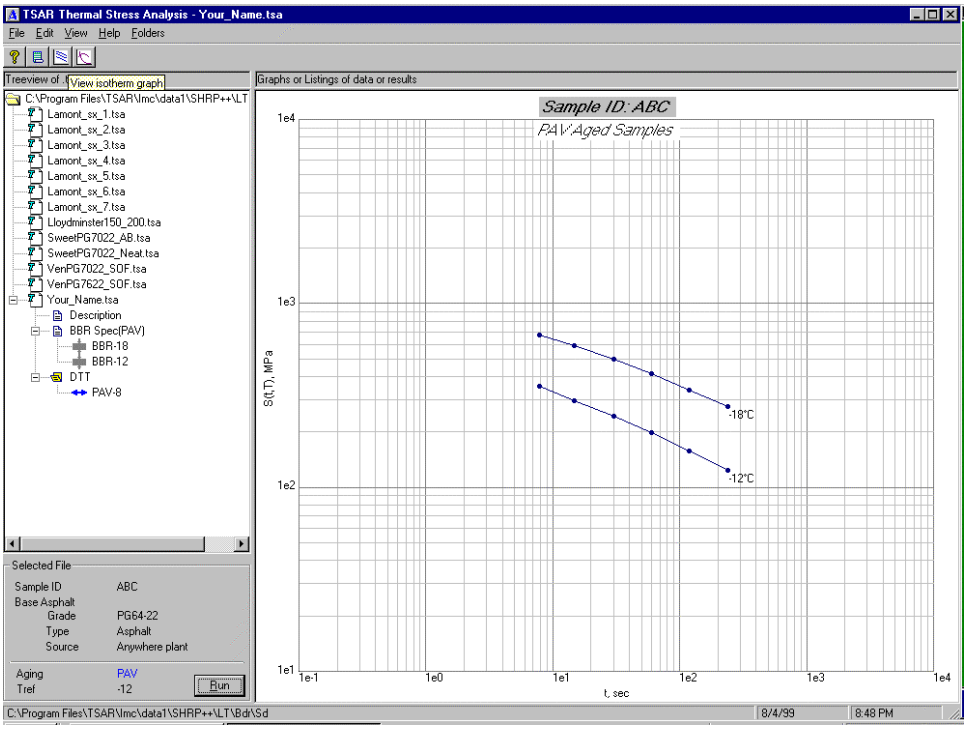
The test data may be viewed by clicking on the "+" sign in the tree. As the data is viewed the Run will become active at the bottom of the screen.



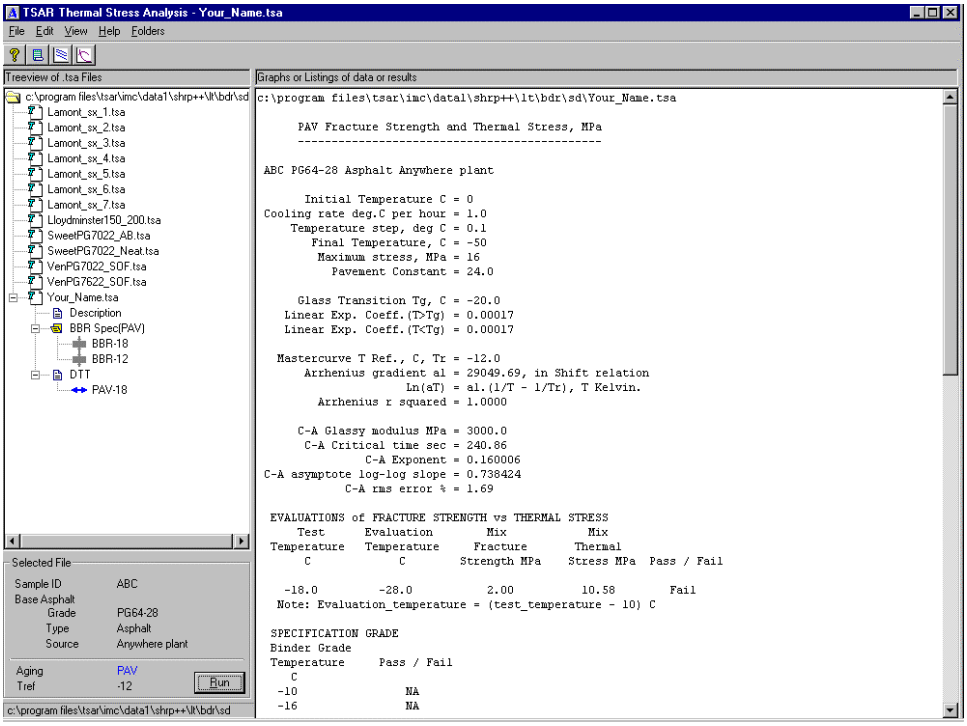
Click the "Run" to execute the analysis. Note: the graphing icons at the top of the screen will become active. Clicking on these gives the results, as follows:



Thermal Stress Graph



Isotherm Graph



Report Listing

The report can be printed out or "cut-and-pasted" into other applications.

Report Listing

The output in the report listing can be cut and pasted into any application. It is advisable to use a constant width font such as Courier.

In this example the report identifies that this binder has "failed" the specification at -18°C. If additional DTT data points are used then the exact grading can be determined.

```
C:\Program Files\TSAR\Imc\data1\SHRP++\LT\Bdr\Sd\Your_Name.tsa

PAV Fracture Strength and Thermal Stress, MPa
      ---------------------------------------------

 ABC PG64-28 Asphalt Anywhere plant

       Initial Temperature C = 0
 Cooling rate deg.C per hour = 1.0
     Temperature step, deg C = 0.1
        Final Temperature, C = -50
         Maximum stress, MPa = 16
           Pavement Constant = 24.0
```

```
     Glass Transition Tg, C = -20.0
   Linear Exp. Coeff.(T>Tg) = 0.00017
   Linear Exp. Coeff.(T<Tg) = 0.00017

  Mastercurve T Ref., C, Tr = -12.0
      Arrhenius gradient a1 = 29049.69, in Shift relation
                     Ln(aT) = a1.(1/T - 1/Tr), T Kelvin.
        Arrhenius r squared = 1.0000

     C-A Glassy modulus MPa = 3000.0
      C-A Critical time sec = 240.86
               C-A Exponent = 0.160006
C-A asymptote log-log slope = 0.738424
           C-A rms error % = 1.69
```

For further explanation of these parameters see section -

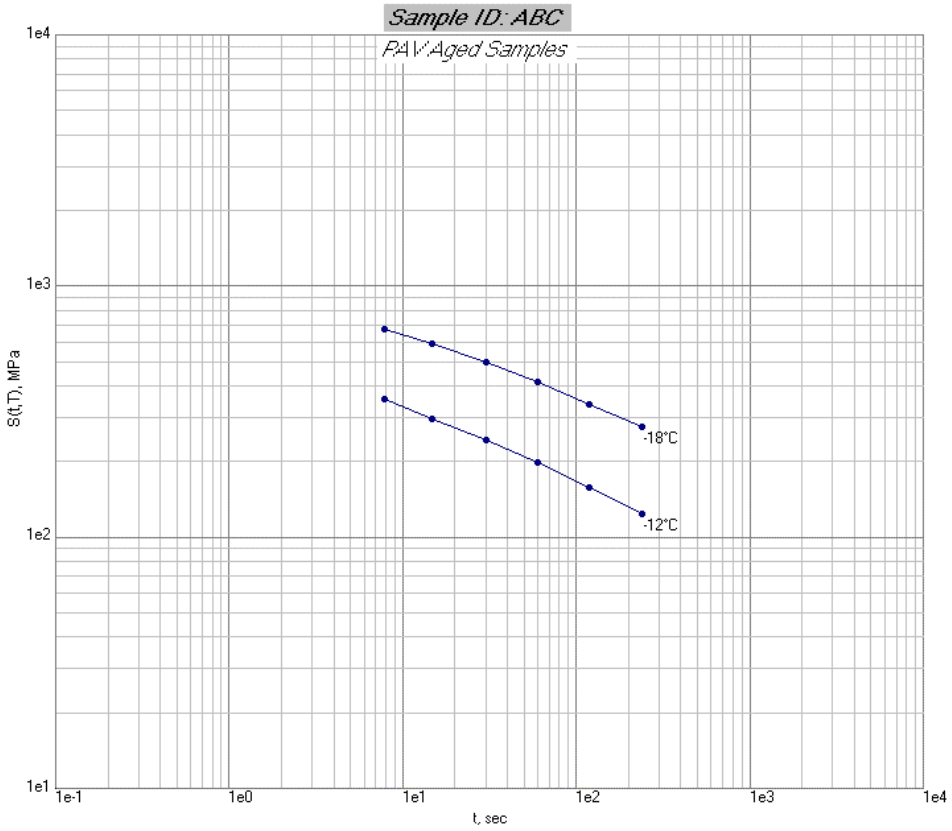
TSAR Plus™, Master Curves

```
 EVALUATIONS of FRACTURE STRENGTH vs THERMAL STRESS
     Test      Evaluation        Mix            Mix
 Temperature   Temperature     Fracture       Thermal
      C             C        Strength MPa    Stress MPa  Pass / Fail

   -18.0         -28.0           2.00          10.58        Fail
  Note: Evaluation_temperature = (test_temperature - 10) C

 SPECIFICATION GRADE
 Binder Grade
 Temperature     Pass / Fail
    C
  -10               NA
  -16               NA
  -22               NA
  -28               Fail
  -34               NA
  -40               NA
  -46               NA

  Predicted Critical Cracking Temperature = NA

 THERMAL STRESS LISTING
                    Binder          Pavement
 Temperature        Thermal          Thermal
      C           Stress MPa      Stress MPa

     0.0             0.00            0.01
    -1.0             0.00            0.02
    -2.0             0.00            0.04
    -3.0             0.00            0.05
    -4.0             0.00            0.07

    -5.0             0.00            0.09
    -6.0             0.01            0.12
    -7.0             0.01            0.16
    -8.0             0.01            0.20
    -9.0             0.01            0.26

   -10.0             0.01            0.32
   -11.0             0.02            0.41
   -12.0             0.02            0.51
   -13.0             0.03            0.64
   -14.0             0.03            0.79

   -15.0             0.04            0.98
```

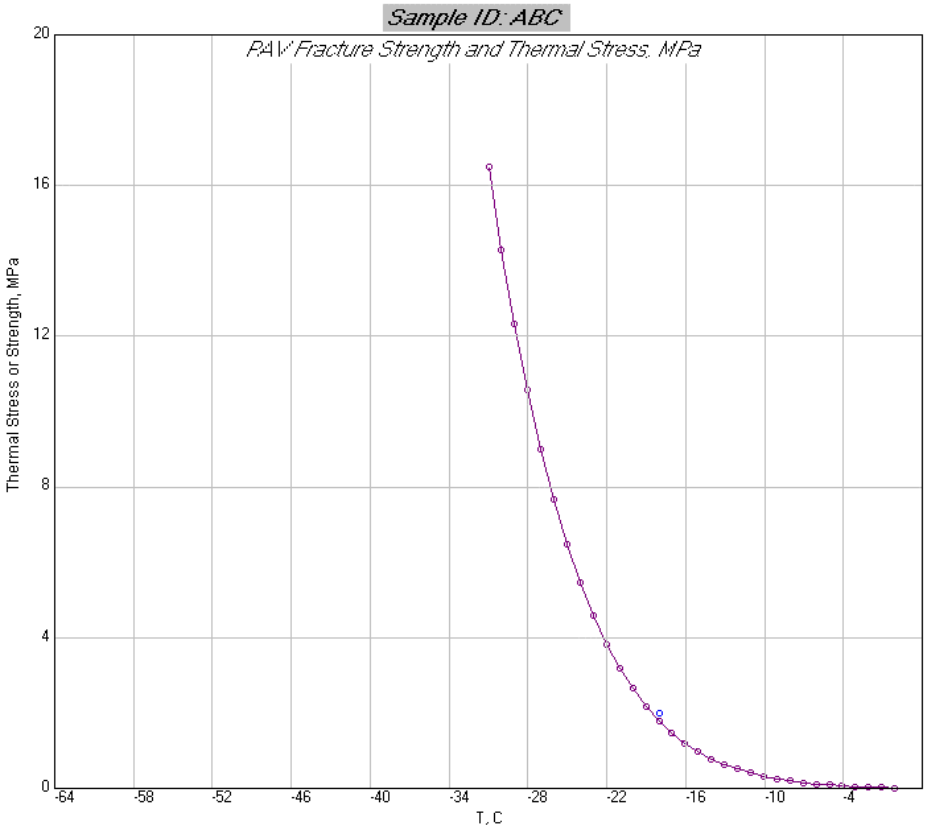
-16.0	0.05	1.20
-17.0	0.06	1.47
-18.0	0.08	1.80
-19.0	0.09	2.19
-20.0	0.11	2.65
-21.0	0.13	3.20
-22.0	0.16	3.85
-23.0	0.19	4.60
-24.0	0.23	5.48
-25.0	0.27	6.51
-26.0	0.32	7.68
-27.0	0.38	9.03
-28.0	0.44	10.58
-29.0	0.51	12.33
-30.0	0.60	14.30
-31.0	0.69	16.52

Graphical Output

Using the copy button the graphs can be extracted from the program and then pasted in any other application using a graphical format of a 16-color bitmap.



Isotherm Graph



Thermal Stress Graph

TSAR Plus™

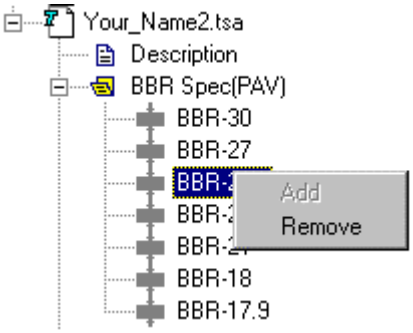
TSAR Plus™ offers the user many advanced functions that are not available with **TSAR™**. These advanced features are described in the various sections below.

- Isotherms
- Master curves
- General Settings
- Thermal stress calculation

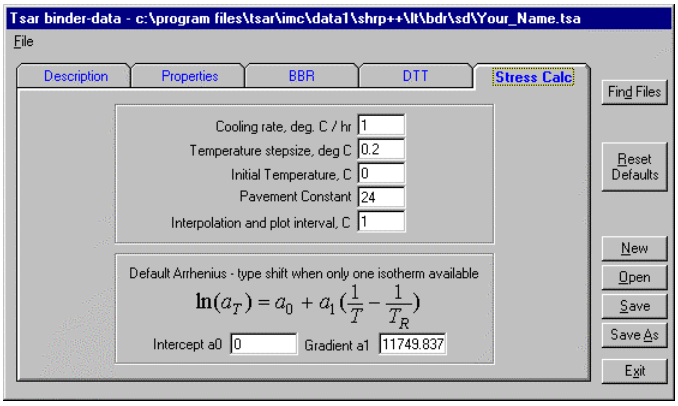
Isotherms

In **TSAR Plus™** the user is able to investigate the effect of including more isotherms in the analysis. All isotherms must be measured at unique temperatures and if more than one measurement exists at a single temperature the arithmetic mean should be used. The user is able to exclude isotherms from the analysis by using the Add/Remove facility provided on the tree. This does not effect the data stored in the "tsa" data file but allows the user to look at the impact of different isotherms on the analysis.

In addition, a single isotherm can be used for analysis with **TSAR Plus™**, which may be considered useful for some aspects of QA/QC or for research needs. If a single isotherm is used then default parameters are used for the shift factors.



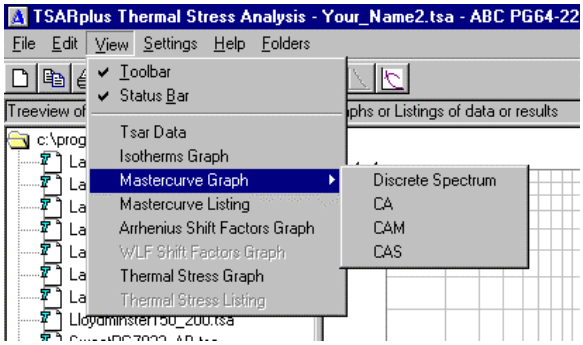
Should the user wish - these shift factors can be changed by editing the data set and then changing the properties in the "**Stress Calc**" Tab. This Tab also contains the default entries for the thermal stress calculations which **TSAR Plus™** users can change. The significance of these parameters are discussed later in this document.



Master curves

The user can choose to display the master curve using one of four models by selecting the model using the ***view-mastercurve*** selection.

Notes:
1. All the models use ξ as the reduced time.
2. The output presented in the report depends on the model selected.
3. The default model used in the software is the CAM.



The models are as follows:

Christensen-Anderson (CA):

$$S(\xi) = S_{glassy}[1 + (\xi / \lambda)^{\beta}]^{-1/\beta} \quad (1)$$

S_{glassy} is a constant ($3*10^3$ MPa) and λ and β are fitted.

Christensen-Anderson-Marasteanu (CAM)

$$S(\xi) = S_{glassy}[1 + (\xi / \lambda)^{\beta}]^{-\kappa/\beta} \quad (2)$$

S_{glassy} is a constant ($3*10^3$ MPa) and λ, β and κ are fitted.

Christensen-Anderson-Sharrock (CAS):

$$S(\xi) = S_{glassy}[1 + (\xi / \lambda)^{\beta}]^{-1/\beta} \quad (3)$$

S_{glassy}, λ and β are fitted.

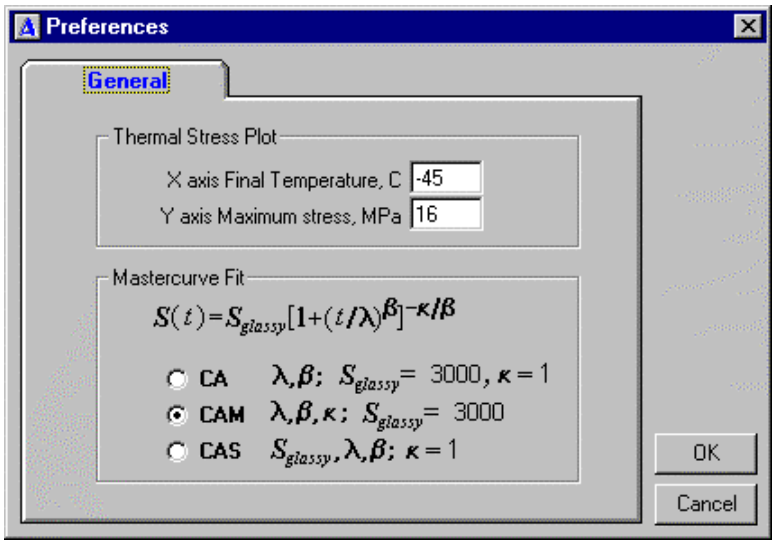
Discrete spectrum (DS):

$$S(\xi) = S_{glassy} \sum_{i=1}^{n} S_i \cdot e^{-\xi/\lambda_i} \quad (4)$$

In this method "*n*" is numerically optimized and the relaxation strengths, g_i, relaxation times, λ_i, estimated.

NOTE: THE DISCRETE SPECTRUM IS PROVIDED TO ALLOW USERS TO GET A MASTER CURVE WITH RELAXATION STRENGTHS AND TIMES. THE SOFTWARE DOES NOT ALLOW COMPUTATIONS OF THERMAL STRESS IF THIS TYPE OF MASTER CURVE IS SELECTED.

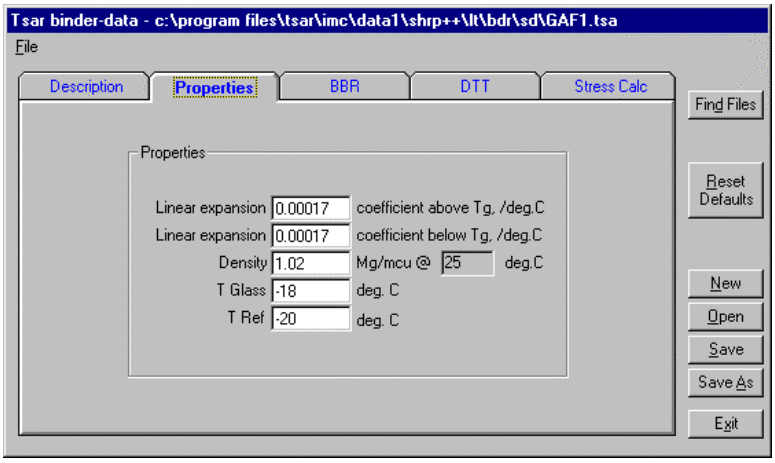
The selection of the master curve analysis method is made using the options provided under preferences. The options set here only apply to the TSAR Plus™ mode. The two other options on this window effect the graphical scaling as described below.



Thermal Stress Calculation

The thermal stress calculation is dependent upon a number of factors that can be varied in the TSAR Plus™ version of the software. Some of these factors can significantly effect the results of the calculation, whereas, others have only a minor influence on the results.

All the default factors are listed in the data set for **TSAR Plus™** on the two additional tabs. The user can at any time reset these to the AASHTO default parameters by pressing the **Reset** button.



Linear Expansion

The user can set a linear expansion coefficient above and below a glass transition temperature. This value does vary with mixture and binder type and has a significant effect on the calculated results. However, measurement is complex and time consuming. The default value is 0.00017/^{o}C.

Glass Transition Temperature

Glass Transition Temperature (T Glass) can be used to define the point at which the linear expansion coefficient changes. If the same value of linear expansion is used either side of T Glass then this parameter has no effect on the calculation.

Reference Temperature

While this does not effect the calculated thermal stresses significantly users may wish to have output of master curves at a particular reference temperature for a variety of reasons. The reference temperature must lie within the range of temperatures for which isotherms are available.

Cooling Rate

The cooling rate significantly effects the calculated result. In the AASHTO procedure a rate of 1^{o}C/hr was considered appropriate. However, users may wish to investigate the effect of different rates upon the expected cracking temperature.

Temperature Step Size

A value of 0.2^{o}C was chosen as default.

Initial Temperature

The initial temperature used in the calculation process should be high enough to ensure that the starting value does not have a significant effect on the computed result. A value of 0^{o}C was selected as default.

Final Temperature to allow

Effects the graphical output, x-axis. Has no effect on the calculated numbers.

Maximum Stress to allow

Effects the graphical output, y-axis. Has no effect on the calculated numbers.

Interval for storing results

We suggest that this be set at 1°C. Changing this number has a very minor effect on the results.

Pavement Constant

A calibration constant (24) used to adjust binder results to field conditions. This has a significant effect on the calculated results.

Report Options

TSAR Plus™ contains additional report options that allow the user to obtain raw data and calculated master curves. The data can be cut and pasted into applications such as Word. Again it is recommended that a font such as Courier be used. If the data is saved as a text file then the data can be imported into spreadsheet applications such as Excel for further analysis.

TSAR Data

This report outputs the data used in the calculations. The first and second lines contain the file details and the constants used in the analysis. Below is the data set for a calculation that included 7 isotherms.

```
Your_Name2.tsa ABC PG64-22 Blown Canada PAV Aged Samples
N 7 -23.1 -20 1 1 0.00017 0.00017 1.02 0
-17.9 6
     8   242    1
    15   204    1
    30   166    1
    60   134    1
   120   106    1
   240    83    1
-18 6
     8   245    1
    15   206    1
    30   169    1
    60   137    1
   120   108    1
   240    85    1
-21 6
     8   336    1
    15   288    1
    30   239    1
    60   196    1
```

```
   120   158    1
   240   125    1
-23.9 6
     8   458    1
    15   394    1
    30   333    1
    60   276    1
   120   226    1
   240   182    1
-24.1 6
     8   459    1
    15   397    1
    30   333    1
    60   277    1
   120   226    1
   240   183    1
-27 6
     8   616    1
    15   539    1
    30   461    1
    60   391    1
   120   323    1
   240   264    1
-30 6
     8   757    1
    15   675    1
    30   583    1
    60   498    1
   120   424    1
   240   351    1
```

Apparent Stiffness Mastercurve Listing

This report gives the shifted master curve data. The results are given in Log Time and Log Transient Modulus.

```
c:\program files\tsar\imc\data1\shrp++\lt\bdr\sd\Your_Name2.tsa

               Time-Temperature Superposition
               ------------------------------

 ABC PG64-22 Blown Canada

     Glass Temperature =  253.2 K   -20.0 C
 Reference Temperature =  250.1 K   -23.1 C


               Results using Transient Modulus
```

Temp., K (C)	Log Shift	Log Time	Log Transient Modulus
243.2 (-30.0)	1.20 +/- 0.03		
		-0.295	2.891
		-0.022	2.841
		0.279	2.777
		0.580	2.709
		0.881	2.639
		1.182	2.557
246.2 (-27.0)	0.73 +/- 0.02		
		0.175	2.796
		0.448	2.738
		0.749	2.670
		1.050	2.599
		1.351	2.516
		1.652	2.428
249.1 (-24.1)	0.15 +/- 0.01		
		0.751	2.663
		1.024	2.600
		1.325	2.524
		1.626	2.444
		1.927	2.356
		2.228	2.264
249.3 (-23.9)	0.15 +/- 0.00		
		0.757	2.662
		1.030	2.597
		1.331	2.524
		1.632	2.442
		1.933	2.355
		2.234	2.261
252.2 (-21.0)	-0.39 +/- 0.01		
		1.298	2.523
		1.571	2.456
		1.872	2.375
		2.173	2.289
		2.474	2.195
		2.775	2.093
255.2 (-18.0)	-0.92 +/- 0.02		
		1.826	2.381
		2.099	2.305
		2.400	2.219
		2.701	2.128
		3.002	2.025

```
                                    3.303         1.921

   255.3 ( -17.9)   -0.95 +/- 0.03
                                    1.851         2.375
                                    2.124         2.301
                                    2.425         2.212
                                    2.726         2.119
                                    3.027         2.017
                                    3.328         1.911

 Variable units identical to those of data.

 Estimate of Arrhenius Constants
    a0 =   0.0000     a1 =  11148.9     R^2 =   0.9987
```

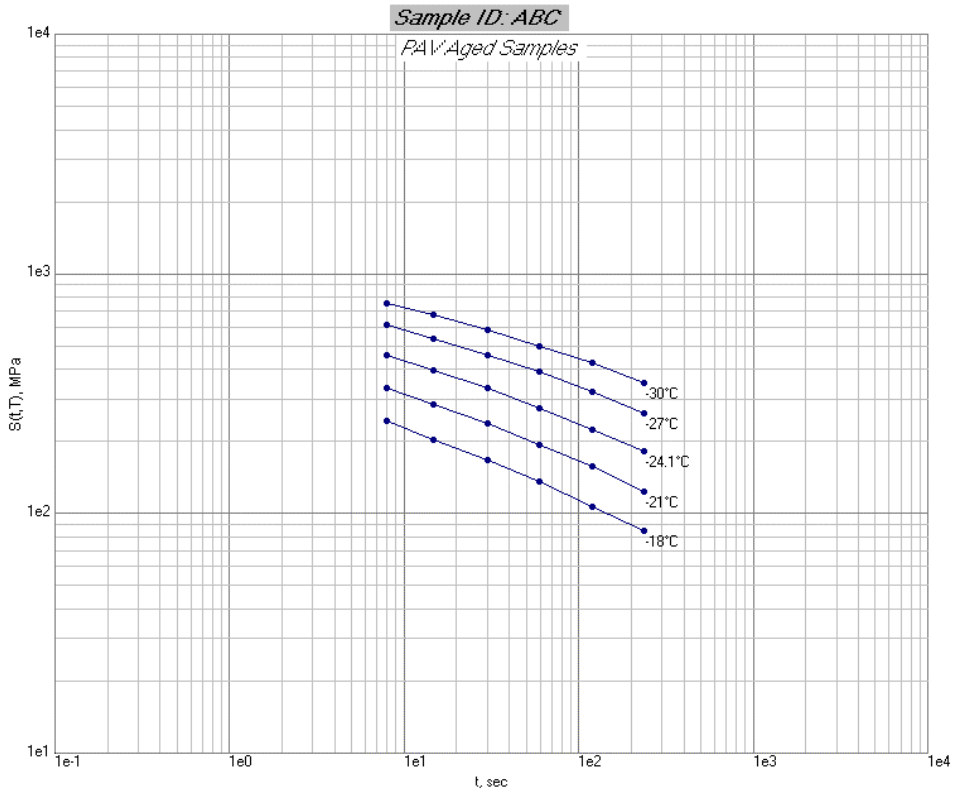
Thermal Stress Results Listing

The information presented here is similar to that produced in **TSAR™**. However, the report includes a warning that the data has been run with **TSAR Plus™** and may not conform to the standards of the AASHTO specification. In addition, the report contains parameters associated with the analysis.

Graphical Reporting

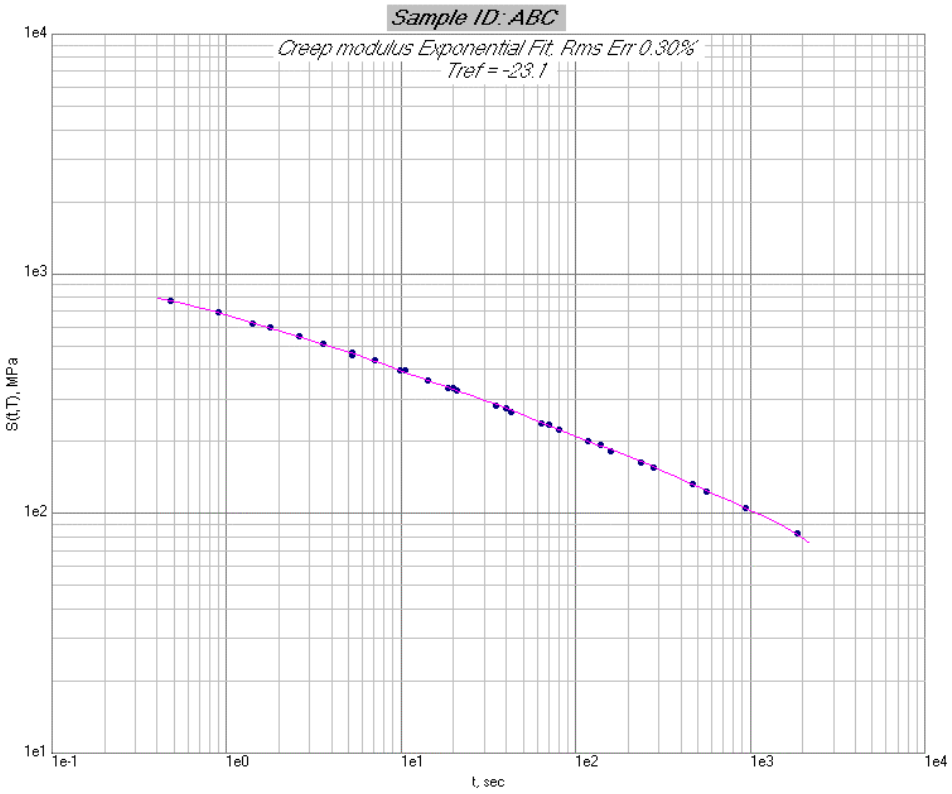
Apparent Stiffness Isotherms

This graph displays the stiffness isotherms for those selected. This graph like others can be cut and pasted into other applications.



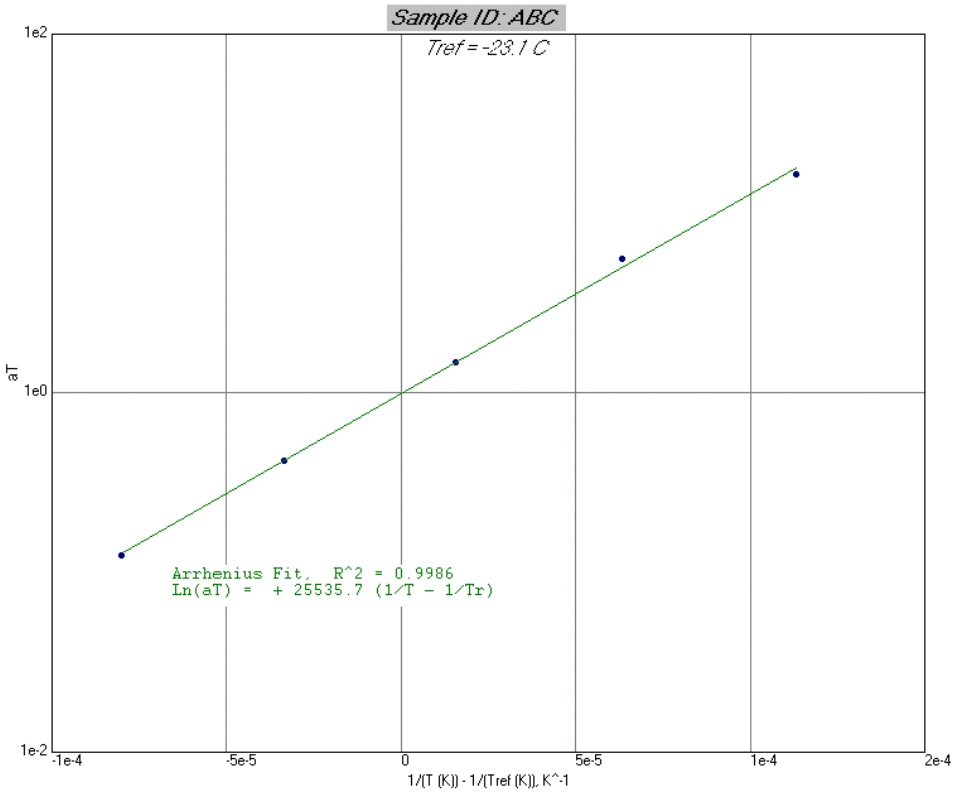
Apparent Stiffness Mastercurve

The stiffness master curve illustrates the master curve for the selected method. The example shown illustrates a Discrete Spectrum fit using the above five isotherms. This method generally gives the best fit in terms of percent root mean square error. However, this method is not used to produce thermal stress curves in the TSAR Plus™ software.



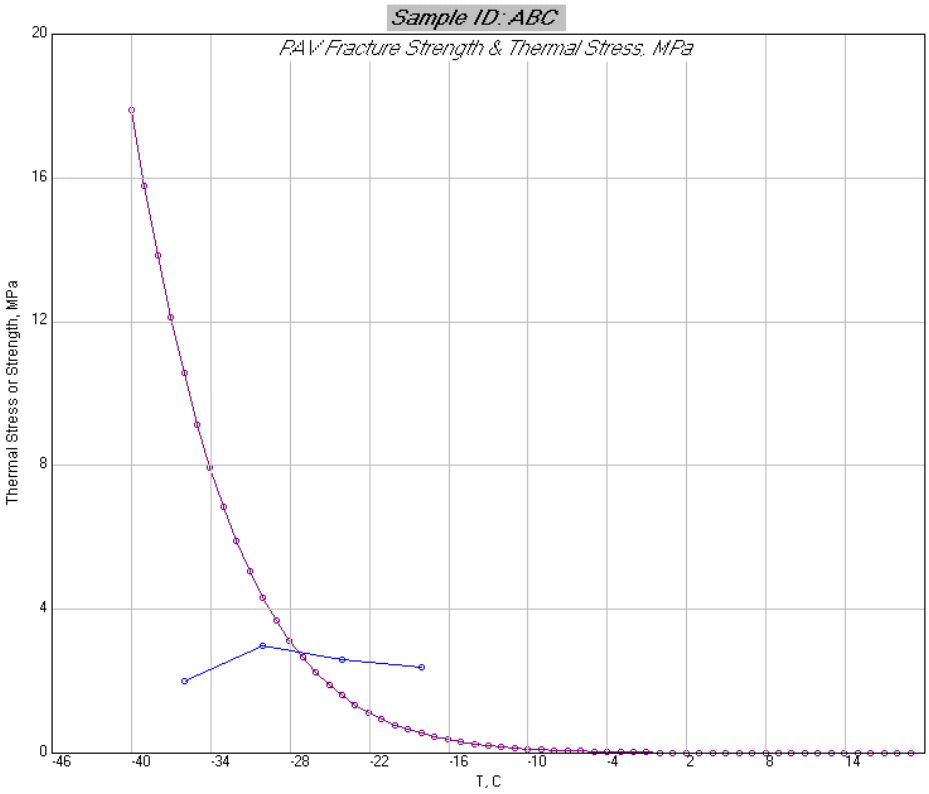
Arrhenius Fitting

Shift factors are based upon the Arrhenius method.



Thermal Stress Results

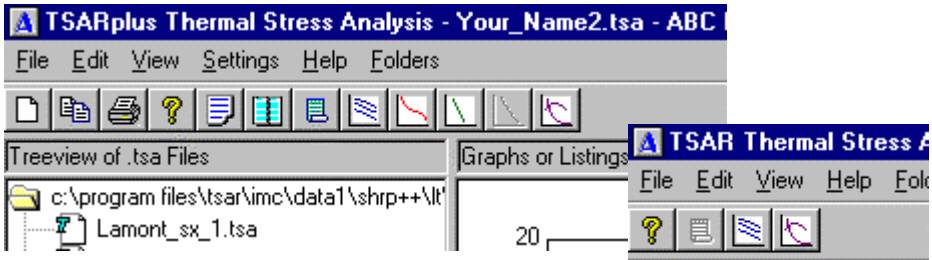
The thermal stress plot illustrates a case were 5 isotherms have been used along with 4 DTT results. The user in this case can determine the exact grade (T_{crit}) since sufficient DTT data points have been used to determine the intercept with the calculated thermal stress curve.


Sample ID: ABC
PAV Fracture Strength & Thermal Stress, MPa
Thermal Stress or Strength, MPa
20
16
12
8
4
0
-46
-40
-34
-28
-22
-16
-10
-4
2
8
14
T, C

Other General Features

Tool bar

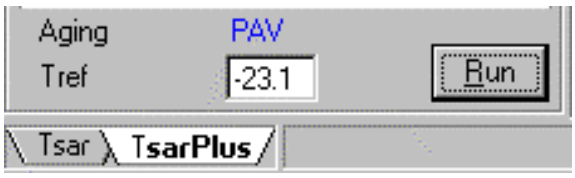
TSAR™ and TSAR Plus™ have a series of buttons on the top of the screen. These buttons have been provided with tool tips. The graphing buttons become active after various part of the analysis has been run. The thermal stress reporting button becomes active after the thermal stress graph has been viewed. This sequence exists since the Run button enables the calculation of the master curve while hitting the thermal stress graphing button completes the run with the selected master curve method. The number of buttons shown on the tool bar depends on which software is being run. The TSAR Plus™ has additional user options compared to the standard version of TSAR™ as illustrated below.



The tool bars can be turned on and off by using the **View** area of the menu and selecting the Tool Bar.

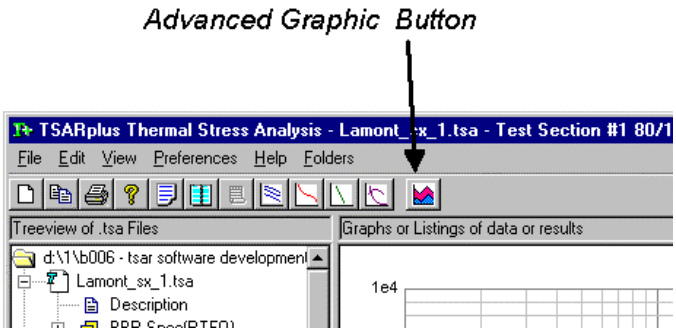
Status Bar

This bar illustrates the current status of the software. In addition, with the TSAR Plus™ the user can switch between TSAR™ and TSAR Plus™ by using the Tab as illustrated.

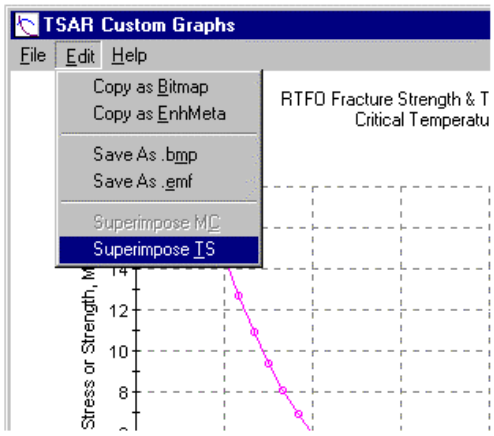


Advance Graphing

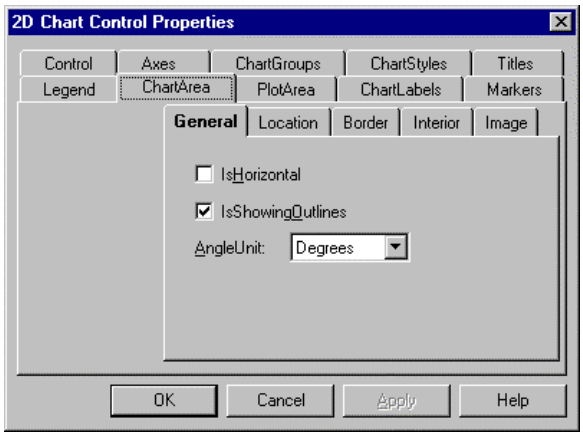
TSAR Plus™ users can make use of advance graphing features to develop sophisticated graphic plots. This utility can be activated from an additional button provided on the menu bar as illustrated below. The graphic utility contains its own help menu and pop-up features for various part of the graph.



When this button is activated the program sends the contents of the active graph to the graphing application without interfering with the calculation in **TSAR Plus™**. The user can then save the data -or- 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



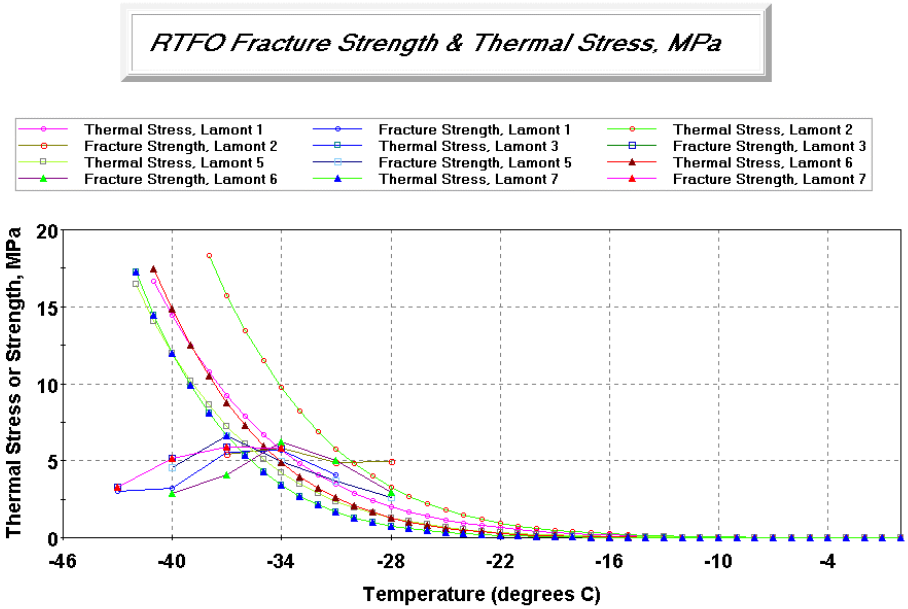
Each feature of the graph can be changed by activating the "2D Chart Control Properties" dialog with a right mouse click. The general box is illustrated below. However, if you activate this dialog box when the mouse is located over a graphic feature - a limited box relating only to that item or feature will be displayed.



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.

Note: The order that you superimpose data sets controls the automatic order that the items are saved in the legend. In the example below we ran the Lamont 1 data set and superimposed onto it already saved data files in the order Lamont 2, Lamont 3, etc. to ensure that the items followed each other in the legend. We then edited the data legends to make them more descriptive and changed the title information.

In addition, to the graphics capabilities of **TSAR Plus™** 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)



Comparision of Lamont RTFO Results

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 (561) 679-2464
Phone (267) 880-1295

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.