Transport
Roads & Maritime
Services

Test method T171

Modified Texas triaxial compression test for pavement materials

OCTOBER 2012

Revision Summary

Ed/Rev Number	Clause Number	Description of Revision	Authorisation	Date
		Reformatted and Revision Summary Added	D. Dash	May 1999
		Date on Test Method Revised to Agree with Date on Revision	D. Dash	Feb 2001
Ed 2/ Rev 0		Revised Issue. Include Addendum T171a. Reformatted. Inclusion of standing period for RAP material. Pronumerals revised. Notes revised. Software investigated. Curves in Appendix.	G Donald	August 2007
Ed 2/ Rev 1	2(f). 7(a), (b)	References added. Accuracy of reporting.	D Hazell	June 2010
Ed 3/ Rev 0	All	Reformatted RMS template	J Friedrich	October 2012

Note that Roads and Maritime Services is hereafter referred to as 'RMS'.

The most recent revision to Test method T171 (other than minor editorial changes) are indicated by a vertical line in the margin as shown here.

Test method T171

Modified Texas triaxial compression test for pavement materials

1. Scope

This test method describes the procedure to determine the shearing resistance of pavement materials (i.e. subbase and base).

NOTE: *This method is based on the Texas Highway Department's test method Tex 117-E-Triaxial Compression Tests for Disturbed Soils and Base Materials.*

2. General

(a) The test applies an axial load to cylindrical specimens supported by various known normal stresses until failure occurs

(b) The test is performed on the portion passing the 37.5 mm AS sieve

(c) Unless otherwise specified, test specimens are prepared at Standard Compaction with the following properties:

(i) 83 to 87% of Optimum Moisture Content (OMC), and

(ii) 99 to 101% of Maximum Dry Density (MDD)

(d) Where an electronic data acquisition system is used to directly capture, record and analyse test data, it must have a precision at least equivalent to the apparatus replaced

(e) The following terms and definitions are used in this Test Method

Term	Definition
Axial load	The sum of the applied load and the dead load and is applied along the vertical axis of the specimen
Axial Strain	The axial deformation of the specimen divided by the original height
Compressive Modulus	The slope of the straight line portion of the axial stress-strain curve (MPa)
Normal stress	The force supplied by air in the cell and applied in a radial direction to the cylindrical specimen (MPa)
Mohr's diagram	A graphical construction used in analysing data from tests on bodies acted on by combined forces in static equilibrium
Mohr's circle of failure	A stress circle constructed from principal stresses acting on the specimen at failure
Mohr's envelope of failure	The common tangent to a series of failure circles constructed from different pairs of principal stresses required to fail the material

(f) The following documents are referred to in this Test Method:

(i) T105 Preparation of Samples for Testing (Soils)

(ii) T111 Dry Density/Moisture Relationship of Road Construction Materials

(iii) T120 Moisture Content of Road Construction Materials (Standard Method)

(iv) AS 1289.5.1.1 Methods of testing soils for engineering purposes - Soil compaction and density tests - Determination of the dry density/moisture content relation of a soil using standard compactive effort

(v) AS 2103 Dial gauges and dial test indicators (metric series)

(vi) AS 2193 Calibration & classification of force-measuring systems

3. Apparatus

(a) A testing machine capable of generating and measuring loads in the range of 0 to 50 kN equipped with the following:

(i) A load-indicating device that meets the accuracy and repeatability requirements of AS 2193 Grade C testing machines for the range of forces used in the test

(ii) Displacement measuring devices to measure sample deformation, capable of measuring the expected range of travel, graduated to 0.1 mm, and meeting the accuracy and repeatability requirements of AS 2103

(iii) Normal pressure measuring device capable of measuring in the range 0 to 160 kPa and meeting the accuracy and repeatability requirements of AS 2193

(iv) Axial cell with dimensions approximately 170 mm internal diameter and 300 mm height, fitted with air connection and tubular rubber membrane approximately 153 mm diameter

(v) A plunger with a spherical end

NOTE: *Where an electronic data acquisition system is used to directly capture and record test data, it must have a precision at least equivalent to the apparatus replaced.*

(b) A pair of hollow metal end blocks of approximately 153 mm diameter

(c) A bearing plate with spherical seat

(d) A vacuum pump

(e) Compressed air supply with pressure regulating valve

(f) A cylindrical metal mould with an internal diameter of 153 ± 0.5 mm and internal effective height of 203 ± 0.5 mm. A detachable base plate and a collar assembly ~50 mm high, both of which can be firmly attached to, or removed from, the mould

(g) A metal rammer with a 50 ± 0.4 mm face diameter and a drop mass of 2.7 kg ± 0.01 kg and equipped with a suitable device to control the height of drop to a free fall of 300 ± 2.0 mm.

NOTE: *A suitable form of hand apparatus is shown in Figure 2 of AS 1289.5.1.1. Provided the essential dimensions are adhered to, mechanical forms of the apparatus may be used.*

(h) A rigid foundation to compact the specimen on (e.g. a concrete floor or a concrete block of at least 100 kg) with suitable attachments for firmly holding the mould base plate assembly during compaction

(i) A heavy duty extrusion frame complete with hydraulic jack of at least 50 kN capacity

(j) A balance of at least 20 kg capacity with a limit of performance of 5g

(k) Mixing apparatus (e.g. steel tray, trowel and scoop)

(l) Metal dishes

(m) A suitably marked depth gauge

(n) A steel straightedge, about 300 mm long, about 25 mm wide and about 3 mm thick, preferably with a bevelled edge

(o) Sealable airtight containers suitable for curing moistened test samples

4. Preparation

(a) Samples shall be prepared in accordance with T105

5. Procedure

5.1 Determination of Sample Characteristics

(a) Determine the maximum dry density (*MDD*) and optimum moisture content (*OMC*) of the sample using Standard Compaction in accordance with T111

(b) Calculate the Target Moisture Content (w_t) as 85% of OMC

(c) Calculate the Target Wet Density (TWD) for the cured sample at the Target Moisture Content (w_t)

$$TWD = MDD \times \frac{(100 + w_t)}{100}$$

Where:

TWD = Target Wet Density (t/m^3)

MDD = Maximum Dry Density (t/m^3)

w_t = Target Moisture Content (%)

(d) Calculate the Target Mass (M_2) required to fill the mould

$$M_2 = V \times TWD$$

$$V = \left(\frac{\pi D_m{}^2}{4 \times 1000} \right) \times h$$

Where:

M_2 = Target Mass (g)

V = Volume of the mould (mL)

TWD = Target Wet Density (t/m^3)

D_m = Average internal diameter of the mould (mm)

h = Height of the mould (mm)

(e) Calculate the required mass (M_L) for each of five (5) equal layers to achieve the Target Wet Density (TWD) as calculated in step (c)

$$M_L = \frac{M_2}{5}$$

Where:

M_L = Required mass per layer (g)

M_2 = Target Mass (g)

5.2 Adjustment of moisture in sub-samples

(a) Calculate the amount of water to be adjusted (M_w) to achieve Target Moisture Content using Process A.10 in T105

NOTE: *A separate sample is required for determination of the initial moisture content. The moisture content of the sample 'w_0' is before any adjustment to moisture.*

(b) Add the water to the sub-sample (M_w) to achieve the Target Moisture Content. Mix the sub-sample to ensure uniform distribution of moisture

(c) Place the sub-sample in a sealed container and cure for a minimum of 12 hours using Process A.6 in T105

(d) Repeat Steps (b) and (c) for each sub-sample

NOTE: *Assumes that the moisture content 'w_0' is the same for all sub-samples.*

5.3 Compaction of specimen

(a) Determine the mass of the mould (M_1) in grams

(b) Determine the combined mass of the upper metal end block and bearing plate (M_D) in grams

NOTE: *The combined mass is an initial surcharge on the specimen and contributes to the load.*

(c) Assemble the mould collar and base-plate and place the assembly on the rigid foundation

(d) Remove the cured sub-sample from the container and mix thoroughly. Cover the sub-sample to prevent loss of moisture

(e) Determine the moisture content of the cured sub-sample (w_c) in accordance with T120

(f) Measure out 5 portions of equal mass (M_L) from the cured sub-sample. Cover each portion to prevent loss of moisture during compaction

NOTE: *Prevent loss of moisture during testing and compaction of each sub-sample.*

(g) Make the specimen by compacting each of the 5 portions in succession as layers of equal thickness in the mould:

- (i) Place the portion (M_L) into the mould and level in a loose state
- (ii) Compact the portion in the mould using uniformly distributed blows from the rammer falling freely over its height
- (iii) Continue compaction until the layer is within ± 2 mm of the required depth. Intermittently measure the depth to top of layer using the gauge. The depth is the average of 5 measurements: one taken in the centre and four equally spaced at the edge of the mould

NOTE: *Allow for the thickness of the collar when measuring the depth.*
Ensure that the gauge is held vertically.

- (iv) Repeat Steps 5.3(g)(i) to (iii)for each of the 5 layers. Slightly scarify the top surface of the first, second, third and fourth layers, before adding the next layer, to ensure adequate bonding between layers. The fifth layer is to be compacted to within -0 mm to +2 mm of the top of mould

(h) Free the material from around the collar and then carefully remove the collar

NOTE: *If the mould is overfilled by more than 2 mm or under filled, the specimen is to be replaced by a new sub-sample.*

(i) Level the specimen to the top of the mould by means of the straightedge. Patch any holes developed in the surface by replacing coarse material with smaller sized material from the sample

(j) Ensure the moisture content of specimens remains constant. Where the sample contains more than 10% of Reclaimed Asphalt Pavement (RAP) material by mass, cover and then stand the sample for seven days at approximately 23°C to allow for the dissipation of pore pressures

NOTE: *Each specimen may be wrapped in damp newspaper and sealed in foil.*

(k) Check that the Target Mass (M_2) has been achieved

- (i) Determine the mass of the mould plus compacted specimen (M_3) in grams
- (ii) Subtract the mass of (M_1) from (M_3) to give the actual mass of the compacted specimen (M_2')
- (iii) If the actual mass (M_2') varies from the Target Mass (M_2) by more than ± 1.0% (by mass) reject the specimen and redo using a new sub-sample

  The variation is calculated as… $\frac{(M_2' - M_2)}{M_2} \times 100\%$

(l) Place a metal end block under the mould and eject the compacted specimen from the mould by means of the heavy duty hydraulic extrusion jack and enclose the specimen in the Texas Triaxial Cell. Place the second metal end block on top of the specimen

5.4 Triaxial Test

(a) The normal stresses (σ'_3) to be used are 10, 30, 60 and 90 kPa

- (i) Centre the specimen with upper and lower metal end blocks in place in the testing machine
- (ii) Centre the bearing plate on the upper end block
- (iii) Raise the platen, align and seat the plunger into the spherical seat of the bearing plate

(iv) Apply just enough load to obtain a perceptible reading on the load gauge. Set the load gauge to zero

(b) Connect the air line to the axial cell and apply the desired normal stress to the specimen

(c) Set the axial strain gauge to zero. Do not reset the load gauge

(d) Turn on the motor with deformation rate of 4.1 mm per minute. Record the load gauge (P_i) at each 0.5 mm increment of deformation (d_i) of the specimen. Continue loading until either the specimen fails or 20.0 mm of deformation occurs. Stop the test and record the maximum load (P_{gauge})

NOTE: Failure is reached when the load gauge readings remain constant or decrease with further increments of deformation.

(e) Remove the upper end block and bearing plate

(f) Remove the specimen from the Texas Triaxial cell

(g) Break up the specimen and determine the moisture content (w_f) of the whole specimen in accordance with T120

(h) Repeat the following steps for each sub-sample until specimens have been tested at the four normal stresses (σ'_3) of 10, 30, 60 and 90 kPa:

(i) Compaction Steps 5.3(d) to 5.3(l)

(ii) Triaxial Test Steps 5.4(a) to 5.4(h)

(i) If the moisture content (w_c) taken in Step 5.3(e) is outside the range 83% to 87% of OMC, the results must be discarded and the point repeated using a new sub-sample

6. Calculations

6.1 Strain and stress

(a) Compute the values of strain, load and stress for each specimen as follows:

$$S = \frac{d_{fail}}{h}$$

Where:

S = Axial failure strain

d_{fail} = Total vertical axial deformation at failure (mm)

h = The height of the original specimen (mm)

$$P_{max} = P_{gauge} + \frac{(M_D \times 9.81)}{1000}$$

Where:

P_{max} = The total vertical load on the specimen at failure (kN)

P_{gauge} = Maximum applied load measured by the load gauge (kN)

M_D = The combined mass of the upper metal end block and bearing plate mass (g)

$$\sigma'_1 = \frac{P_{max}}{A} \times (1 - S)$$

Where:

σ'_1 = The corrected maximum vertical stress at failure strain (kPa)

P_{max} = The total vertical load on the specimen at failure (kN)

S = Axial failure strain

A = Area of the end of the cylindrical specimen at the beginning of test (m^2)

NOTE: A correction is necessary because the area of the cross-section increases as the specimen is deformed. The assumption is that the specimen deforms at constant volume.

6.2 Mohr's Envelope of Failure

(a) Each specimen tested provides one pair of values (σ'_1, σ'_3). Calculate the co-ordinates of the point of maximum shear stress (p', q') for each Mohr's circle as follows:

NOTE: *Usually there will be 4 maximum shear stress points (p', q') corresponding to the 4 normal stresses of 10, 30, 60 and 90 kPa.*

$$p' = \frac{(\sigma'_1 + \sigma'_3)}{2}$$

$$q' = \frac{(\sigma'_1 - \sigma'_3)}{2}$$

Where:

p' = The normal stress at the centre of a Mohr's circle (kPa).

q' = The maximum shearing stress (kPa).

σ'_1 = The corrected maximum vertical stress at failure strain (kPa).

σ'_3 = The normal stress (kPa).

(b) Determine the linear correlation of the failure envelope based on the maximum shear stress points on the Mohr's diagram. Compute the shear stress intercept (a), angle of slope (α) and the correlation coefficient (r) as follows:

$$a = \frac{\sum p'^2_i \times \sum q'_i - \left(\sum p'_i\right) \times \left(\sum p'_i q'_i\right)}{n\sum p'^2_i - \left(\sum p'_i\right)^2}$$

$$\alpha = \tan^{-1}\left[\frac{n\sum p'_i q'_i - \left(\sum p'_i\right) \times \left(\sum q'_i\right)}{n\sum p'^2_i - \left(\sum p'_i\right)^2}\right]$$

$$r = \frac{n\sum p'_i q'_i - \left(\sum p'_i\right) \times \left(\sum q'_i\right)}{\sqrt{\left[n\sum p'^2_i - \left(\sum p'_i\right)^2\right] \times \left[n\sum q'^2_i - \left(\sum q'_i\right)^2\right]}}$$

Where:

- a = The shear stress intercept of the linear correlation on the Mohr's diagram (kPa).
- α = The angle of slope of the linear correlation on the Mohr's diagram (°).
- r = The correlation coefficient to 4 decimal places.
- p' = The normal stress at the centre of a Mohr's circle (kPa).
- q' = The maximum shearing stress (kPa).
- i = The i^{th} result for a test series numbered from 1 to n.
- n = Number of (p', q') pairs (i.e. conforming tests).

(c) If $r < 0.99$, examine the Mohr's circles and investigate the specimen moulding details (i.e. moisture content and dry density) to determine whether a result can be justifiably removed from the analysis

Where a result is removed from the analysis note the justification and repeat Step (b)

NOTE: Only one point may be removed from the analysis.

(d) Repeat the whole series if the resulting analysis has an $r < 0.99$

(e) Compute the Angle of Shear Resistance (ϕ_u) and Apparent Cohesion of the material (C_u) as follows:

$$\phi_u = \sin^{-1}(\tan \alpha)$$

$$C_u = \frac{a}{\cos(\phi_u)}$$

Where:

- ϕ_u = Angle of shear resistance (°)
- C_u = The apparent cohesion of the material (kPa).
- α = The angle of slope of the line of best fit through all maximum shear stress points on the Mohr's diagram (°).
- a = The shear stress intercept of the line of best fit through all maximum shear stress points on the Mohr's diagram (kPa).

6.3 Average Compressive Modulus

(a) The Compressive Modulus for each test carried out is determined as follows:

(i) Calculate the values and plot the axial stress (σ') and axial strain (S) relationship for a specimen

(ii) Calculate the Compressive Modulus as the slope of the linear section of the stress-strain relationship. However, if the stress-strain relationship is not linear, the Compressive Modulus is the slope of the straight line joining the point of zero axial strain to the point on the plot corresponding to 0.75% of the maximum Axial Strain (S)

(iii) Repeat Step 6.3 (a)(i) and (ii) for each specimen in the series

(b) The Compressive Modulus for each series of tests is the average value of the Compressive Moduli from each test

6.4 Classification of Material

(a) Plot the Mohr's Envelope of Failure $\tau_n = C_u + \sigma_n \tan(\phi_u)$ on the Texas triaxial classification chart (refer to Appendix A)

(b) Classify the material as the Texas Classification that is approximately tangental to the failure envelope. When the envelope of the failure falls between Texas Classes, interpolate the classification to the nearest one-tenth of a classification (refer to Appendix A - A.2)

7. Reporting

Include the following data and results in the report:

(a) For the sample:

(i) Angle of shearing resistance (ϕ_u) to 0.1°

NOTE: Also referred to as 'PHI'

(ii) Apparent cohesion (C_u) to 0.1

(iii) Average Compressive Modulus to 0.1 MPa

(iv) Average Relative Density as a percentage of Maximum Dry Density (% MDD) to 0.1%

(v) Average Relative Moisture content (at moulding w_c) as a percentage of OMC to 0.1%

(vi) Percent retained on 37.5 mm AS sieve to 0.1%

(vii) Texas classification number rounded to one decimal place

(viii) Maximum Dry Density to 0.01 t/m^3

(ix) Optimum Moisture Content to the nearest 0.1%

(x) Target density to 0.01 t/m^3

(xi) Target Moisture Content to the nearest 0.1%.

(b) For each specimen at each Normal Stress (i.e. 10, 30, 60, 90 kPa):

(i) Compressive modulus to 0.1 MPa

(ii) Dry Density of specimen to 0.01 t/m^3

(iii) Relative Dry Density (*MDD*)of specimen to 0.1%

(iv) Moisture Content at moulding (w_c) to 0.1%

(v) Moisture Content after testing (w_f) to 0.1%

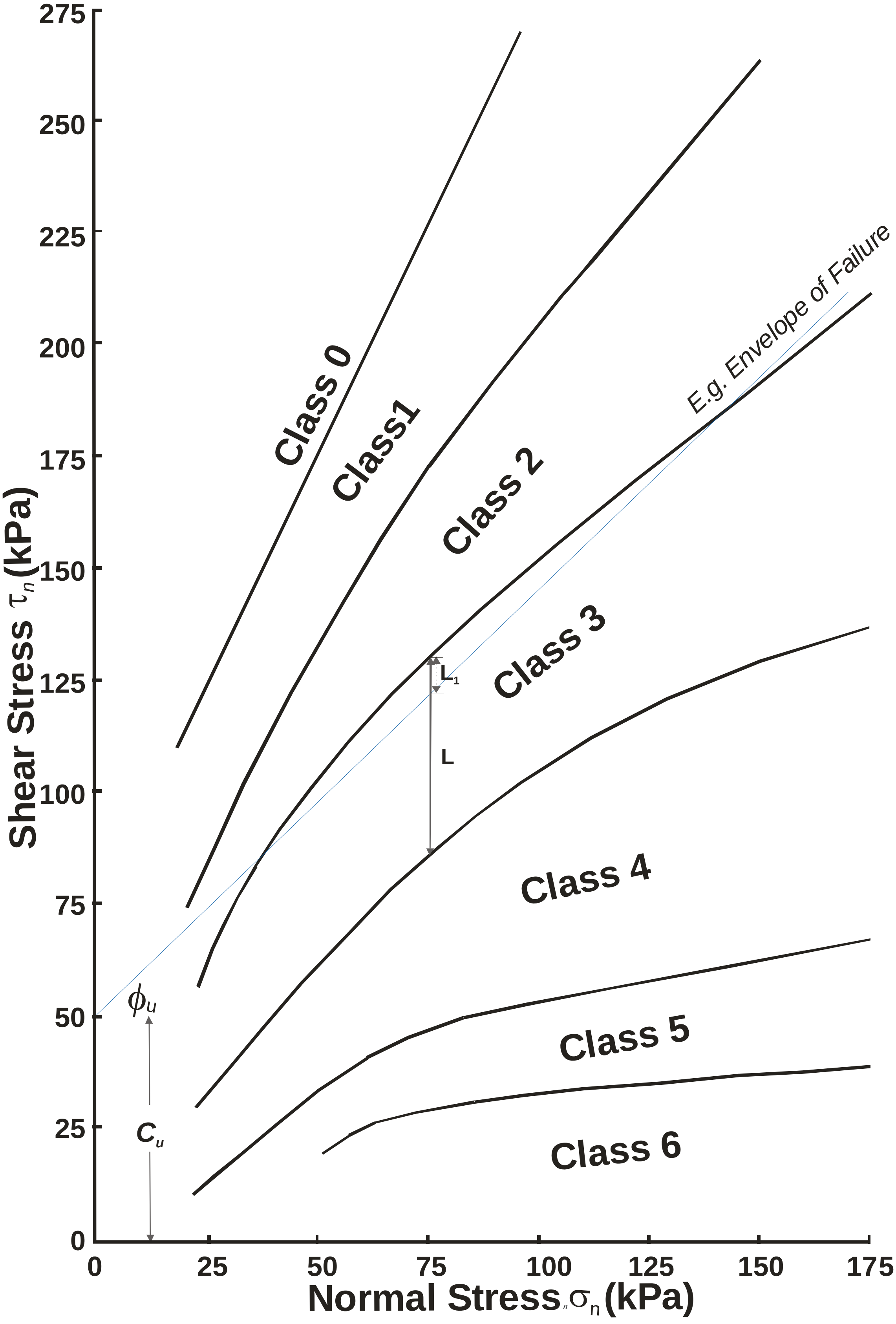
(vi) Relative Moisture Content (at moulding) as a % of OMC to 0.1%

(c) Comment regarding removal (if any) of a result in determining the correlation in Step 6.2(c)

(d) Reference to this Test Method

Appendix A Texas Classification

A.1 Texas Triaxial Classification Chart



NOTE: Curves are only applicable for specimens subject to Standard Compaction.

A.2 Interpolation of Texas Classification Number

When the envelope of failure is located within a Texas Classification, the Classification Number is to be interpolated using the following graphical procedure:

NOTE: *An example is shown on the previous chart and the Texas Classification is 3.2.*

(i) Estimate the point where the Envelope of Failure is most distant from the upper but adjacent Texas Classification and mark the point on the Envelope of Failure

NOTE: *Classification 0 is an arbitrary boundary curve that enables material to be classified to the nearest 0.1.*

For Classification 6 results, interpolate using the normal stress axis as the lower "curve".

(ii) Draw a vertical line through the point and parallel to the Shear Stress axis

(iii) Measure the distance of the vertical line between adjacent Texas Classification Curves in mm (L)

(iv) Measure the distance from the envelope of failure to the lower but adjacent Texas Classification in mm (L_1)

(v) Calculate the ratio of L_1/L as a decimal to the nearest 0.1

(vi) Check other points and select the highest decimal increment

(vii) The Texas Classification Number is the Texas Classification plus the decimal increment