



PLX-Benchtop User Manual



PLASTOMETREX

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1 PLX-Benchtop Introduction

1.1 Introduction

The PLX-Benchtop from Plastometrex, powered by CORSICA software, is a mechanical testing system that extracts stress-strain curves from metallic materials using an indentation test. The system is comprised of three main elements:

1. CORSICA: a local software application for controlling the hardware system and guiding users through the test procedure. The data analysis procedure used in CORSICA enables calculation of tensile stress-strain curves from indentation data through a numerical approach. This technique is known as Profilometry-based Indentation Plastometry (PIP).
2. PLX-Benchtop: a loading frame with indenter and integrated profilometer. See the key components of the PLX-Benchtop in Figure 1.1.
3. PC: provided by the user, used for operating the PLX-Benchtop and the CORSICA software.

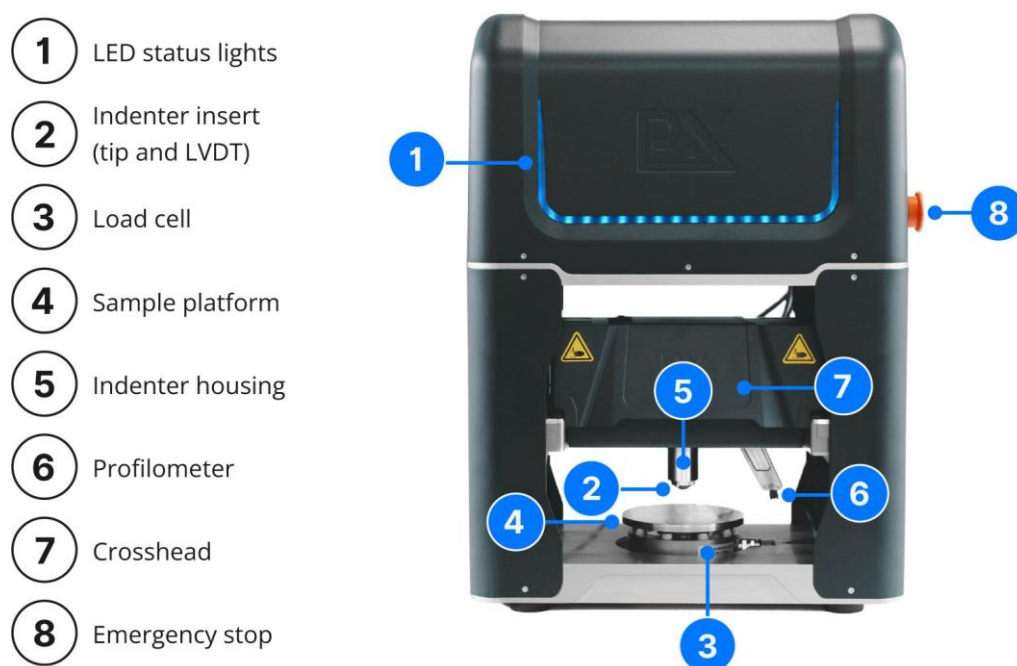


Figure 1.1 Key Components of the PLX-Benchtop

This is Plastometrex's original User Guide for the PLX-Benchtop. All specifications in this document are correct at the time of production and are subject to change. Please contact Plastometrex at support@plastometrex.com for further information.

2 PLX-Benchtop Overview

2.1 Technical Specification

Feature	Requirements
Electrical Supply	220-240 V, 50/60 Hz Class 1 equipment must be connected to an earthed supply. Mains plug acts as disconnect device and should be readily accessible.
Support Surface	Stable bench or table (Machine weight ~ 40 kg)
PC Specification	Windows 10 or Windows 11 operating system CPU with a clock speed of 3.5 GHz or higher At least 16 GB of RAM Standard Ethernet and USB ports
Ethernet	Ethernet connection is local
Force Capacity	8 kN
Overload Characteristics	200%
Load Resolution	0.1 N
LVDT Resolution	0.3 µm
Profilometer Resolution	0.1 - 0.4 µm
Position Control Resolution	1 µm
Indenter Material	Si ₃ N ₄
Indenter Radius	1 mm
Vertical Test Space	70 mm
Horizontal Test Space	70 mm
Height	500 mm
Width	300 mm
Depth	200 mm
Weight	40 kg
Operating Temperature	5 to 40°C
Humidity	10 to 80% non-condensing
Test Materials	Ductile Metallics (Yield Stresses < 3 GPa)
Noise Levels	<70 dBA

Force measurement accuracy

0.5% down to 1/100 of the load cell capacity, 1% from 1/100 to 1/500 of the load cell capacity. Linearity class 0.05% FRO.

Displacement measurement accuracy

$\pm 2 \mu\text{m}$ for a 200 μm indent.

Atmosphere

Designed for use under normal laboratory conditions. Indoor use and maximum altitude 2000 m.

2.2 CE Marking

All systems conform to all relevant European standards and carry CE marking. The CE Marking on the product label indicates that Plastometrex has checked that products meet all applicable EU Essential Requirements, Standards and Directives as declared on the “Declaration of Conformity” included with the product. These specifications were developed in accordance with Plastometrex standard procedures and are subject to change without notice.

UK/EC Declaration of Conformity								
ORIGINAL								
We Plastometrex Ltd Unit 204 Cambridge Science Park, Cambridge, CB4 0GZ declare under our sole responsibility that the product:								
Description	Model	Serial No.						
Indentation Plastometer	PLX-P	PLX-P-0021						
to which this declaration relates are in conformity with all the essential requirements of Machinery Directive 2006/42/EC, EMC Directive 2014/30/EU, RoHS Directive 2011/65/EU and The Supply of Machinery (Safety) Regulations 2008 as amended, The Electromagnetic Compatibility Regulations 2016 as amended and The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012, as amended: The following harmonised standards have been applied with respect to this product: <table> <tbody> <tr> <td>BS EN ISO 12100:2010</td> <td>BS EN 61010-1:2010</td> </tr> <tr> <td>BS EN ISO 13849-2:2012</td> <td>BS EN 61326-1:2013</td> </tr> <tr> <td>BS EN ISO 13850:2015</td> <td>BS EN IEC 63000:2018</td> </tr> </tbody> </table> Person Authorised to compile Technical File Plastometrex Ltd Person Empowered to draw up Declaration Dr. James Dean Chief Executive Signed at: Cambridge, UK September 2023			BS EN ISO 12100:2010	BS EN 61010-1:2010	BS EN ISO 13849-2:2012	BS EN 61326-1:2013	BS EN ISO 13850:2015	BS EN IEC 63000:2018
BS EN ISO 12100:2010	BS EN 61010-1:2010							
BS EN ISO 13849-2:2012	BS EN 61326-1:2013							
BS EN ISO 13850:2015	BS EN IEC 63000:2018							

Figure 2.1 UK/EC Declaration of Conformity

2.3 PLX-Benchtop Safety

If the equipment is used in a manner not specified by the manufacturer, the protection provided by the unit may be impaired.

2.3.1 Crushing hazard

There is a potential crushing hazard when using the machine, particularly to the user's fingers. The machine is marked with four crushing hazard stickers as seen below. Please ensure that fingers are always removed from the test space when the crosshead is moving. Do not place fingers on top of the crosshead cover for any reason.



Figure 2.2 Crushing hazard symbol

2.3.2 Sample suitability

Specimen requirements are given in §3.3 of the PLX-Benchtop manual. Samples that do not meet the requirements and/or present a danger in loading/testing should not be tested – in particular, the sample must be well supported underneath the indenter and not be at risk of toppling under the indentation load.

2.3.3 PPE

Safety goggles should be used when using the machine.

2.3.4 Emergency Stop

The emergency stop is located on the right-hand side of the machine. If the emergency stop is pressed, all automated machine movement will stop. Rotate the emergency stop button to release. The software should recover, and the user should be able to continue.

If the emergency stop was hit due to damage being sustained to the machine, contact Plastometrex at support@plastometrex.com in order to determine the possible damage before continuing to use the equipment.

2.3.5 Transportation

The PLX-Benchtop weighs 40 kg and two people are required to move it. For transportation over long distances, use the custom Peli Case supplied by Plastometrex. Ensure the profilometer is well supported prior to transport. The profilometer arm should be supported by the small clip provided, with the screw tightened in place.

2.3.6 Maintenance and Cleaning

The following procedures are recommended for maintenance and cleaning:

- Carry out the calibration operations regularly, when prompted by the software. The machine set up operation is required when a new tip is installed, and the profilometer calibration is required daily.
- Regular general cleaning is recommended, depending on usage levels and environment. Care should be taken not to damage the profilometer. It is relatively robust, but the tip could be damaged by physical contact. 70% alcohol pads or dampened towels could be used to clean the equipment. Do not use bleach-type products or liquids.

3 PLX-Benchtop Setup

3.1 Machine Setup and Status

3.1.1 Hardware

Ensure that the machine is appropriately connected to a power supply and a computer via both USB and Ethernet. These ports are located on the rear of the machine (please note that the side ports are not used when operating the PLX-Benchtop). Ensure the PLX-Benchtop is switched on using the switch located on the rear of the machine.

The PLX-Benchtop test space refers to all space within the footprint of the machine below the crosshead.

3.1.2 Software

Ensure that the latest version of CORSICA is installed. An active license file must be present on the machine for the software to install!

On launching CORSICA, the boot sequence will be initiated, which is identified by a blue building light sequence. The window shown in Figure 3.1 will be seen on screen. If the PLX-Benchtop does not obtain the “Devices Ready” state (seen bottom left) within 30 seconds, more information can be found by clicking “Show connection status”, which is found under “View”.

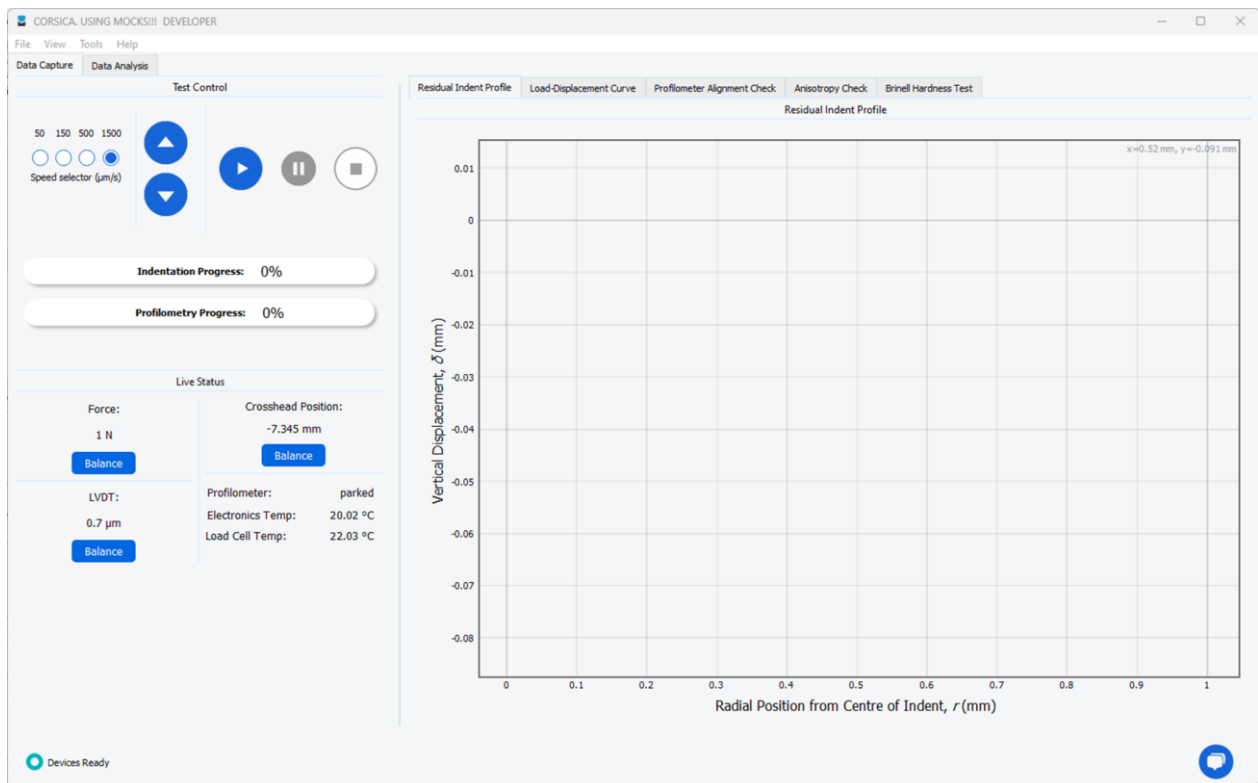


Figure 3.1 The CORSICA – Data Capture window, which appears on opening the software.

When the booting sequence has been completed, the LED status lights will change from building or flashing blue to steady blue and the “Devices Ready” icon will be present in bottom left corner. The machine is now ready to use. Table 3.1 details the meaning of the LED status lights.

Colour	Form	Meaning
Blue	Building/Flashing	Booting
Blue	Steady	Standby
Green	Building	Indentation Progress
Yellow	Building	Profilometry Progress
Purple	Building	Calibration Progress
Red	Flashing	Error

Table 3.1 Meaning of the LED status lights colour display.

3.2 Introduction to CORSICA

The GUI, as shown in Figure 3.1, can be broken down into the following key panels.

3.2.1 Data Capture

3.2.1.1 Test Control

A PIP test is initiated here through the start button (blue play button). This involves the indentation procedure followed by profile capture, for which the progress is indicated on the progress bars. The stop button can be used at any point during automated machine operation. Positioning of the crosshead is achieved using the appropriate arrow for movement up and down. The speed should be chosen carefully to avoid damage to the sample and the user.

3.2.1.2 Live Status

This provides the user with status readings for the load cell, crosshead displacement, and LVDT, and includes the ability to balance them. Please ensure that the Force and LVDT values reflect the status of the PLX-Benchtop before starting a test (and Balance them if necessary). Temperature in the top casing and profilometer status are also displayed.

3.2.1.3 Plots

The user can toggle between the load-displacement plot and various profile plots from a test.

3.2.2 Data Analysis

3.2.2.1 Load Files

Indentation files can be uploaded with the **Open File** button or cleared with the **Reset all** button. Tabulated results – tensile properties, Voce plasticity parameters (by clicking the “?” button) and Brinell hardness number for an indent are presented. Results can be exported in PDF or csv form using the **Export** section.

3.2.2.2 Plots

The user can toggle between the stress-strain curve and indent profiles from a test.

3.3 Sample Placement and Preparation

Sample requirements for a PIP test are detailed in Table 3.2. Samples that do not meet these requirements and/or present a danger in loading/testing should not be tested. The sample should be well supported underneath the indenter and not be at risk of toppling under the indentation load.

Feature	Requirements
Sample Dimensions (1 mm Radius Tip)	Thickness range: 3 mm to 70 mm Lateral range: 6 mm to 150 mm
Sample Dimensions (0.5 mm Radius Tip)	Thickness range: 1.5 mm to 70 mm Lateral range: 3 mm to 150 mm
Sample Dimensions (0.25 mm Radius Tip)	Thickness range: 0.75 mm to 70 mm Lateral range: 1.5 mm to 150 mm
Sample Surface Finish	$R_z < 4\ \mu\text{m}$ and $R_a < 0.5\ \mu\text{m}$ P1200 abrasive paper for 1 and 0.5 mm radius tips P2500 abrasive paper for 0.25 mm radius tips
Sample Surface Tilt	Up to 2°
Sample Material	Metallic only
Sample Mounting	Mounted or Unmounted

Table 3.2 Sample Requirements

The following procedure is used to insert a sample in the PLX-Benchtop ready for PIP testing. It is also applicable to calibration samples.

1. Check that the machine is in standby mode (constant blue LED), with the profilometer in the parked position.
2. The crosshead should be moved to a suitable height, such that the sample can be placed under the indenter tip, with the LVDT just above the sample surface (not in contact). This is carried out by using the up and down buttons in Test Control.
3. Place the sample on the platen under the indenter tip. The proposed test location should be approximately under the indentation axis, although users will be prompted to fine-tune the position prior to the test.
4. For large samples, care must be taken to not position the sample such that any part of it is close to the profilometer, which is parked well to the right of the platen (Figure 3.2).
5. The sample must be positioned such that the LVDT (the axis of which is 5 mm to the right of the indenter axis) will touch the sample surface when the crosshead is lowered (Figure 3.2). If the LVDT misses the sample, it could result in damage to the sample surface. For small samples, it may be easier to manually lower the crosshead close to the sample to ensure this criterion is met.
6. For very small samples, the user may have to mount the sample for the LVDT to hit an equivalent sample surface. Ideally, the LVDT will be directly on the sample surface, however in this case the LVDT could contact the adjacent mount surface, although this could have a small adverse effect on the outcome. Further detail on mounting samples is provided in §6.4.
7. The indent location should not be within 5 mm of an existing indent or 3 mm of a free edge for the 1 mm radius tip. Distances are halved for the 0.5 mm radius tip and quartered for the 0.25 mm radius tip.

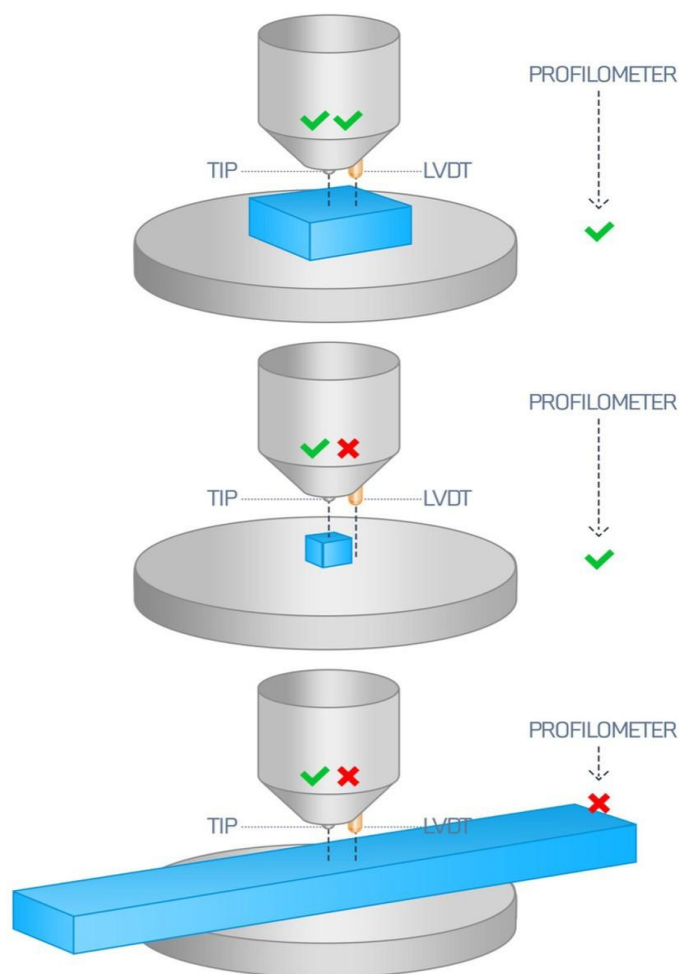


Figure 3.2 Sample placement guide

3.4 Machine Set Up and Calibrations

Table 3.3 shows the recommended calibration frequency for the machine set up, profilometer calibration, and load cell calibration. CORSICA will prompt the user to perform the calibration when necessary.

Operation	Frequency
Machine Set Up	On installation, yearly, and when the tip is changed
Profilometer Calibration	Every 3 hours or if the top casing temperature changes by 2.5°C
Load Cell Calibration	Yearly

Table 3.3 Calibration Frequency

The machine set up operation and profilometer calibration ensure that the signals produced by both the LVDT and the profilometer are being correctly converted to heights (z values) and that the relative (x, y, z) locations of the indenter tip, LVDT and profilometer tip have been correctly established.

3.4.1 Machine Set Up

The Machine Set Up operation can be accessed through **Tools > Machine Set Up**. This operation automatically carries out the LVDT Calibration, the Working Distances Calibration, and the Indent Centre Search. A sample that can be indented should be placed on the PLX-Benchtop platen for this operation:

3.4.1.1 LVDT Calibration

This operation takes about 90 seconds. It correlates the signal of the LVDT with the crosshead displacement. The procedure is as follows:

1. The indenter housing moves downward until the LVDT touches the sample surface.
2. The indenter housing moves downward at a fixed (slow) speed, periodically recording the LVDT output signal.
3. The indenter housing is retracted so that it is well clear of the sample.

3.4.1.2 Working Distances Calibration

This calibration takes about 3 minutes. It involves finding the height of the profilometer and indenter tip relative to that of the LVDT, allowing use of the LVDT to monitor the height of the sample surface. The procedure is as follows:

1. The indenter housing moves downward until the LVDT touches the sample surface.
2. The indenter housing then continues to move down until the indenter touches the sample surface.
3. The indenter housing is retracted.
4. The profilometer moves across to the (x, y) location of the indentation axis.
5. The profilometer moves down until it touches the sample surface.
6. The profilometer is retracted and then returned to its parked position.

3.4.1.3 Indent Centre Search

This operation takes about 2 minutes. It is aimed at ensuring that the profilometer can be moved to the (x, y) location of the indentation axis after each indent has been created. The following steps are involved:

1. The indenter housing moves downward until the LVDT touches the sample surface.

2. A dialogue box will appear, allowing the user to manually move the sample in the (x-y) plane until the indenter is above a suitable (flat) location:
3. The sample is moved, if necessary, and the “Continue” button is clicked. A safety dialogue box will appear. Ensure that the testing area is clear and confirm when ready to continue.
4. The indenter housing is brought down, creating an indent. The indenter housing is retracted.
5. The profilometer moves across to the (x, y) location of the indentation axis.
6. A dialogue box now appears, for positioning of the (x, y) location of the profilometer so that it can scan the indent. This is done via the x- and y-direction arrows within the dialogue box.
7. Move the profilometer so that it is above the indent – this is done with the appropriate arrows on screen. **Do not move the sample manually for the operation, only use the arrows.** It is important that the tip is positioned such that the tip is aligned with centre of the indent in the x direction. This should be checked visually, looking through the workspace, as shown in Figure 3.3. When this is lined up close to the centre, use the y control to do the same in the y direction – this is less critical in terms of getting close to the indent, but an attempt should be made to get as close as possible. When this is completed, click “Yes”.
8. The profilometer carries out a series of scans in the (x-y) plane, until the location of the centre of the indent has been established and this (x, y) location used to calibrate its x and y coordinates.
9. A dialogue box appears. A final scan of the indent is carried out, and this profile is displayed. The profilometer returns to its parked position. The procedure is then terminated by Clicking on “Finish”.

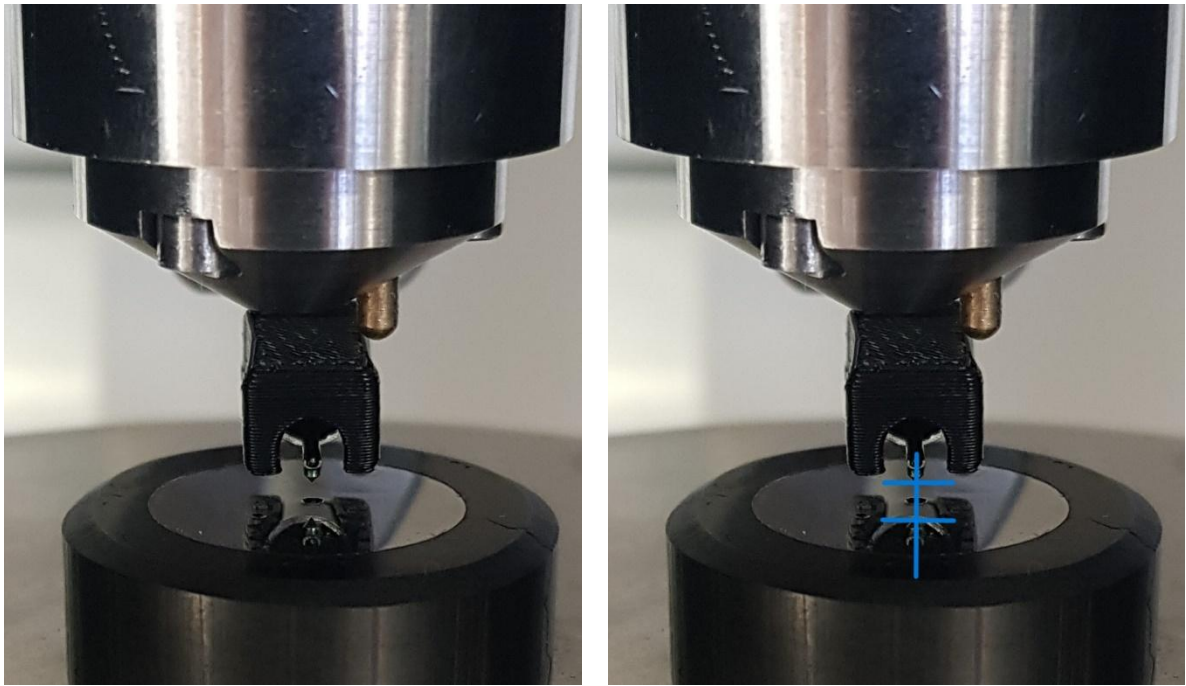


Figure 3.3 Profilometer positioning guide

3.4.2 Profilometer Calibration

This operation takes about 5 minutes. It involves calibrating the profilometer signal using an indent with known dimensions. CORSICA will prompt the profilometer calibration based on both time (3 hours) and temperature fluctuations ($\pm 2.5^{\circ}\text{C}$). The procedure is as follows:

Place the profilometer calibration sample (provided by PLX) on the platen and position it as shown in Figure 3.2. The indent should be located approximately on the indentation axis. If this calibration sample is lost or damaged, please contact Plastometrex at support@plastometrex.com.

1. Go to **Tools > Calibrate > Profilometer**. When ready, click “Start”.
2. A dialogue box will appear. The value of the depth of the calibration sample indent should be input. This can be found on the calibration sample and sample box. Click on “OK” when this is done.
3. The indenter housing moves downward until the LVDT touches the sample surface.
4. The indenter housing is retracted.
5. The profilometer moves across to the (x, y) location of the indentation axis.
6. A dialogue box now appears, for positioning of the (x, y) location of the profilometer so that it can scan the indent. This is done via the x- and y-direction arrows within the dialogue box.

7. Move the profilometer so that it is above the indent – this is done with the appropriate arrows on screen. It is important that the tip should be positioned such that it is aligned with centre of the indent in the x direction. This should be checked visually, looking through the workspace, as shown in Figure 3.3. When this is lined up close to the centre, use the y control to do the same in the y direction – this is less critical in terms of getting close to the indent, but an attempt should be made to get as close as possible. When this has been completed, click “Yes”.
8. The profilometer carries out a series of scans in the (x-y) plane, until the location of the centre of the indent has been established (and the depth at that point has been used to calibrate its output). The profilometer returns to its parked position.
9. A dialogue box appears. Click on “Finish”. Retrieve the calibration sample.

3.4.3 Load Cell Calibration

The Load Cell Calibration procedure should be carried out annually. It requires a load cell calibration unit and a thermocouple from Plastometrex, which can be sent to the user on request. Please note that the user will be responsible for the cost of renting or purchasing the required equipment. To perform a load cell calibration:

1. Move the crosshead to the top of its range by using the moving arrows. When the top limit switch is activated, move the crosshead down a few millimetres.
2. Connect the load cell calibration device and thermocouple (if provided) supplied by Plastometrex via USB to your PC.
3. Place the load cell calibration device and the provided sample on the PLX-Benchtop load cell platen. The thermocouple should be located near the reference load cell.
4. Go to **Tools > Calibrate > Load Cell** and start the procedure.
5. The calibration is fully automated and takes approximately 30 minutes.

Please contact Plastometrex at support@plastometrex.com to carry out your annual load cell calibration.

4 CORSICA Operation

4.1 Data Capture

With the machine setup and calibrations complete, the PLX-Benchtop is ready to use. The main functionality of Data Capture is the production of an indent and the capture of the residual profile.

1. Place the sample within the test space on the platen, as described in §3.3.
2. Click the start button located in Test Control. Input file name, directory, and material type. The option is also given to populate PLXUS Database for the sample. At this point, an optional Brinell test can also be included. Once this is done, click Start.
3. The indenter housing moves downward until the LVDT touches the sample surface. The machine will pause and a dialogue box will appear, allowing the user to manually move the sample in the (x-y) plane until the indenter is above a suitable (flat) location. This is a final chance to adjust the indent location. Do not indent too close to a free edge or another indent, as outlined in §6.5. Click Yes when ready to indent.
4. A safety dialogue box will appear. Ensure that the testing area is clear and confirm when ready to continue.
5. The indenter housing moves slowly downwards and indentation starts. The load-displacement plot is progressively created during loading
6. The sample is unloaded and the indenter housing is retracted above the sample.
7. The profilometer moves quickly across to the (x, y) location of the indentation axis.
8. A quick search for the precise indent centre is carried out. The profilometer scans the indent. After completion of the scan, the resultant profile is displayed on the screen, as shown in Figure 4.1.

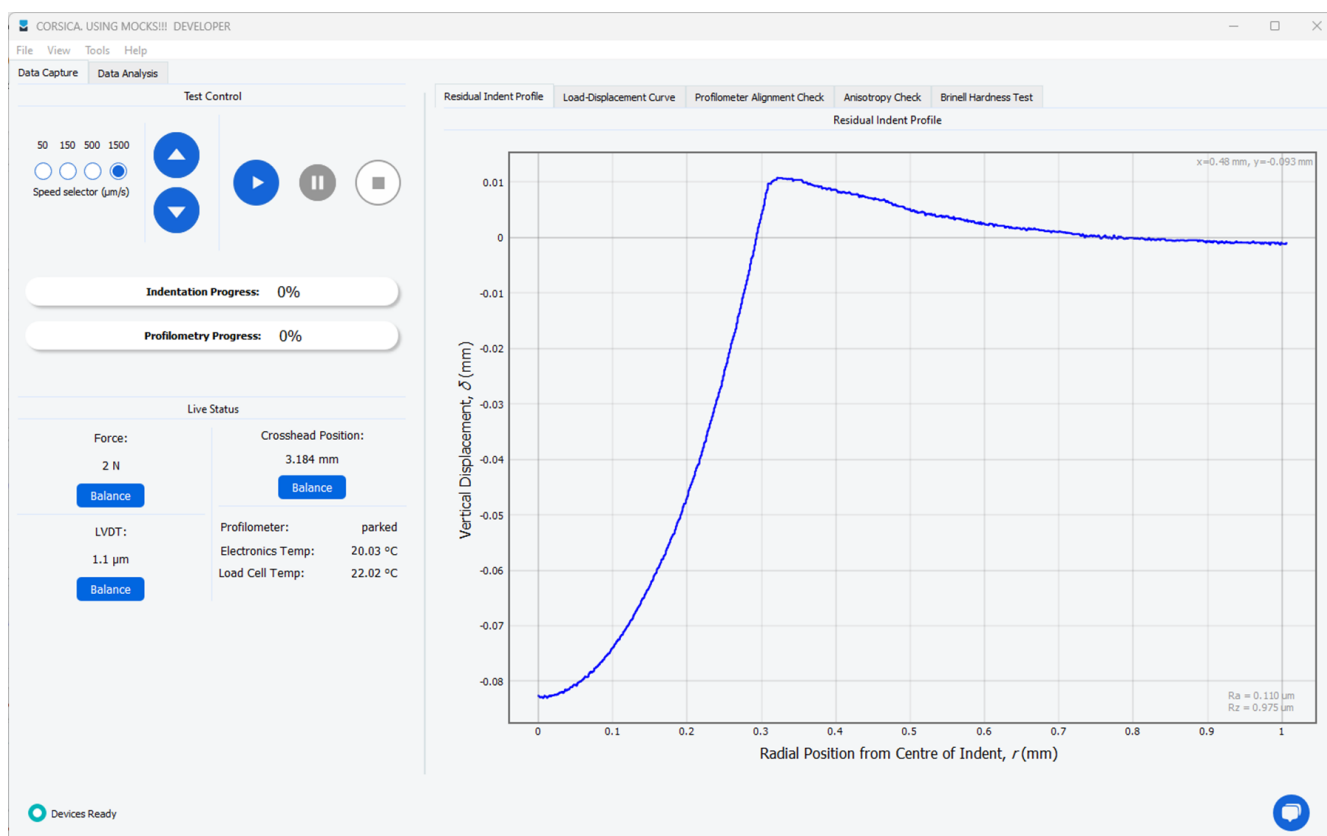


Figure 4.1 Post-profilometry window

9. Following the first scan (in the x direction), y, xy, and yx scans are carried out. This is done to identify in-plane anisotropy in the sample. Further information can be found post-test in the Test Diagnostics panel. This will include a warning if anisotropy is detected.
 - An in-plane anisotropy check is made for all indents. This involves comparing the x, y, xy, and yx scans of the indent. If there is greater pile-up in one direction, this direction can be assumed to be softer than the others. The PLX-Benchtop will identify 3 levels of anisotropy: minimal, intermediate, and significant. For anisotropy levels deemed to be significant the data analysis cannot be performed. It should be noted that anisotropy parallel to the indentation direction cannot be picked up.
 - For each profile scan carried out, a tilt calculation and surface roughness measurement are made. The values are used by the software to warn the user of potential errors that may be encountered, although these do not actually prevent the user from continuing. If a warning is given and an error follows, guidance is provided in the error message on how to proceed. To avoid associated errors, ensure that the indentation surface is normal to the indentation axis and that the surface roughness is suitably low.

10. The profilometer returns to its parked location.
11. The Test Diagnostics window provides information pertaining to the test that was just carried out. The user should consult the Test Diagnostics for warnings (highlighted in yellow) and errors (highlighted in red). An option to move on to Data Analysis is presented - click "Transfer to Data Analysis" when ready.

The plot options specific to the data capture are the Load-Displacement Curve, The Residual Profile, Profilometer Alignment Check, Anisotropy Check and the Brinell Profile.

4.2 Data Analysis

A test file may be transferred from Data Capture (**Transfer to Data Analysis**) or located via the browse function (**Open File**) and loaded into Data Analysis. The analysis is carried out automatically, after which the screen shown in Figure 4.2 appears.

For each test, the following can be found in the Data Analysis Control Panel. Further information about these outputs can be found in the relevant more information button.

– Tensile stress-strain curve outcomes

Yield Stress (σ_Y) - The yield strength presented with a confidence bound.

Ultimate Tensile Strength (σ_{UTS}) - The peak value of the nominal stress is displayed. The confidence bound is provided as a range.

Necking strain - The strain at UTS.

– Brinell Hardness

If the Brinell option is activated in the test protocol, the Brinell hardness value will be measured and presented.

– Voce Plasticity Parameters

The best-fit values of the plasticity parameters in the Voce equation are obtained by clicking the "?" button next to Plasticity Formulation: Voce. These are the yield stress (σ_Y), the saturation stress (σ_s) and the characteristic strain (ϵ_0).

– Test Diagnostics and Results Interpretation

The option to bring up the "Test Diagnostics" summary shown at the end of data capture test is given. "Results Interpretation" gives further information about interpreting the PIP results.

– Data Export

The ability to export the data in PDF and CSV form are provided. Each of these include user options so exports can be tailored to the user's requirements.

– Stress-strain curve

The inferred stress-strain curve is plotted in tensile nominal and true form. The Voce parameters will determine the form of both curves.

– Indentation Profile

The residual indent profiles measured during Data Capture will be shown with the best-fit FEM profile.

– Brinell Profile

The profile from the Brinell test is shown with the indent width (used to calculate the Brinell hardness value) marked on.

Figure 4.2 shows the CORSICA Data Analysis GUI for a typical PIP test. The stress-strain relationship is the primary output of the PIP test. The nominal curve is obtained from the true data via the standard conversion equations. This conversion is only valid while the stress and strain fields are uniform within the gauge length of the sample -i.e. up to the onset of necking. The key tabulated data relating to the tensile curve plot are found in the “Tensile Properties” section of the GUI.

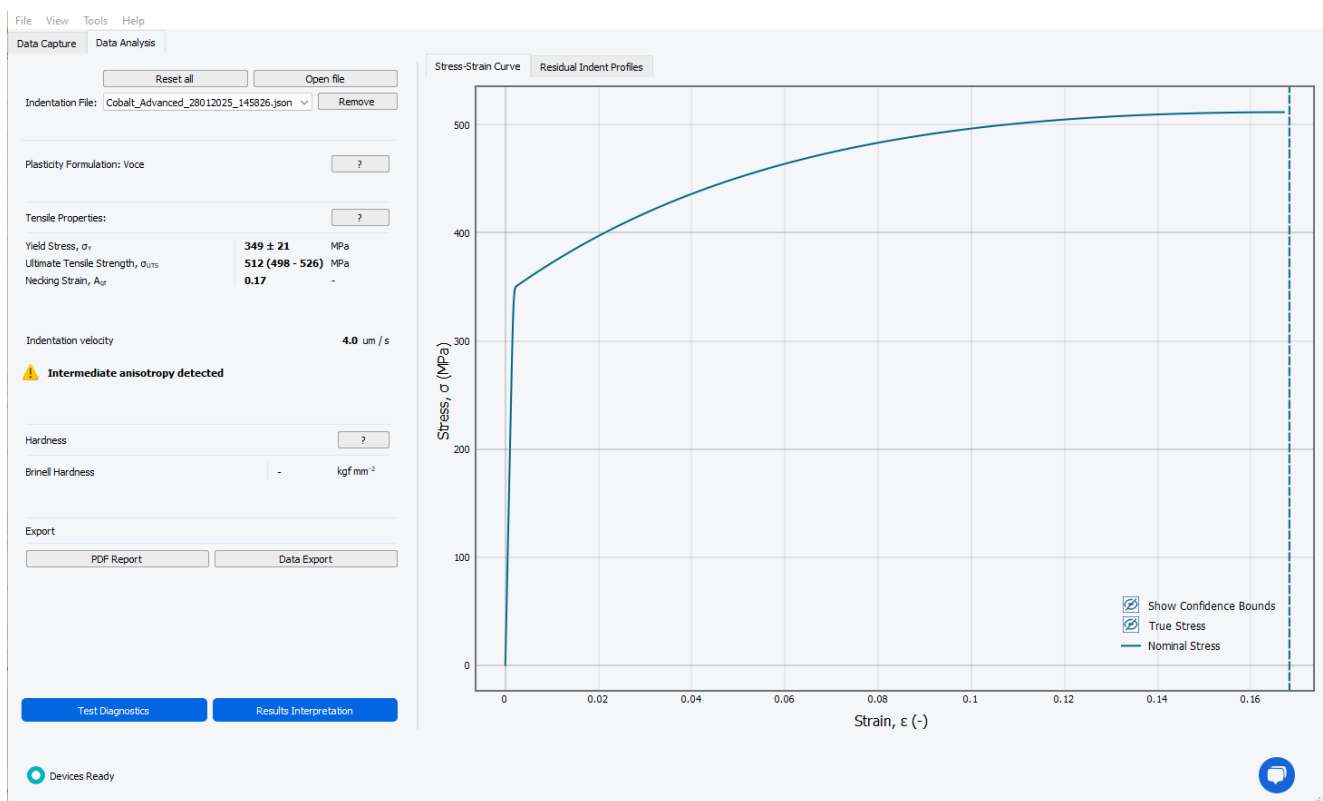


Figure 4.2 Data Analysis window

4.3 Advanced Functionality

4.3.1 Brinell Test

Hardness can be thought of as a measure of the resistance that a material offers to plastic deformation. They are commonly measured and reported due to the ease of measurement. They are however not a fundamental material property and therefore should be used with caution – different testing arrangements (test load and tip shape) may yield different hardness values. Although conversion charts for obtaining yield and UTS values from hardness numbers are commonplace, this practice should be used with caution. Both the yielding and work hardening characteristics will contribute to the hardness value you measure and compensate for each other in a way which means no universal conversion exists.

A Brinell Hardness test may be included in the testing protocol for each test done – this will provide the user with the Brinell Hardness on top of the plasticity characteristics. The standards for the Brinell test (ASTM - E10 and ISO - 6506-1) specifies a series of tip diameters – 1 mm diameter is one of these, but the 2 mm diameter is not, however, both are optional tip sizes on the PLX-Benchtop. There is no reason not to use a 2 mm diameter tip, but the loads must be appropriately scaled.

For each tip diameter, a Force-Diameter Ratio (given as F_{kgf}/D^2) will determine equivalence between tip sizes. A final point of note, the standards state the test should be carried out with a tungsten carbide tip – the PLX-Benchtop uses a silicon nitride tip, which will give very similar values. CORSICA is setup to allow the user to select from three different Force-Diameter Ratios, these are given in Table 4.1.

Force-Diameter Ratio	Equivalent to the following Brinell Tests	Recommended for Hardness Range HBW
30	HBW 10/3000, HBW 5/750, HBW 2.5/187.5, HBW 1/30	95.5 to 650
10	HBW 10/1000, HBW 5/250, HBW 2.5/62.5, HBW 1/10	31.8 to 218
5	HBW 10/500, HBW 5/125, HBW 2.5/31.25, HBW 1/5	15.9 to 109

Table 4.1 Brinell hardness equivalence guide

The Brinell hardness number is defined as the load divided by the contact area. This is normally obtained using the following expression:

$$H_b = \frac{2F}{\pi D \left[D - \sqrt{D^2 - d^2} \right]}$$

where F is the applied load (in kgf), D (mm) is the diameter of the indenter and d (mm) is the diameter (in projection view) of the indent.

4.3.2 Advanced Indentation Parameters

With Advanced Indentation Parameters enabled, the following indentation parameters can be modified:

- **Indentation Velocity:** Controls the rate at which the indenter moves into the sample during testing.
- **Test Types:**
 - Load Controlled: The test is performed up to the specified load value.
 - Depth Controlled: The test is performed up to the specified indentation depth.
- **Dwell Time:** Determines the duration for which the indenter is held at the peak load during the test.

The screenshot shows the 'Indentation Test' dialog box. At the top, there are fields for 'Directory' (set to 'C:\Users') and 'File name' (set to 'test'), with a 'Browse' button next to the directory field. Below these are checkboxes for 'Append timestamp' (checked) and 'Append load point' (unchecked). A section for 'Include Brinell Hardness Test' has three radio buttons: 'Equivalent to F/D = 30' (selected), 'Equivalent to F/D = 10', and 'Equivalent to F/D = 5'. There are two dropdown menus for 'Saved Material Database' and 'Material Type', both set to '--Please select--'. A checkbox for 'Populate PLXUS data' is unchecked. The 'Indentation Parameters' section is expanded, showing 'Indentation velocity' set to '8.10 um/s' and 'Advanced Indentation Parameters' checked. Below this, 'Test Type' is set to 'Depth Controlled', 'Indent Depth' is '171 um', and 'Dwell time' is '0 s'. At the bottom, there are buttons for 'Test Setup Info', 'Cancel', and 'Start'.

Figure 4.3 Advanced Indentation Parameters in CORSICA.

To ensure system integrity, these parameters are password-protected and can only be modified by customers with a CORSICA+ subscription. To obtain the password, please contact your Applications Engineer.

4.3.3 Take Profile

This allows the user to scan the profile of indents that were created in a previous experiment. This may be used if profilometry failed before completion, if the user wants to scan a different orientation of an indent, or to rescan an old indent. To initiate the scan, Material Type and optional PLXUS data must be specified in the same way as when beginning an indent. Additionally, the maximum load at which the indent was carried out and the tip radius are required.

1. Place the sample within the test space, according to the instructions in §3.3. The position to be indented should be located (very approximately) on the indentation axis.
2. Go to **Tools > Take Profile**. A dialogue box appears, within which the user inputs a filename and Material Type, as well as the maximum load, tip radius, and indent speed used to create the indent. Once this has been done, click Start.
3. The indenter housing moves downward until the LVDT touches the sample surface. It is then retracted.
4. The profilometer moves across to the (x, y) location of the indentation axis.
5. A dialogue box now appears, for positioning of the (x, y) location of the profilometer so that it can scan the indent. This is done via the x- and y-direction arrows within the dialogue box. It is important that the tip is positioned such the tip is aligned with centre of the indent in the x direction. This should be checked visually, looking through the workspace, as shown in Figure 3.3. When this is lined up close to the centre, use the y control to do the same in the y direction – this is less crucial in terms of getting close to the indent, but one should try to get as close as possible. When this is completed, click Yes.
6. The profilometer will touch down on the sample surface. A search for the precise indent centre is carried out. The profilometer then scans the indent and the resultant profile is displayed on the screen. The profilometer returns quickly to its parked location.
7. The Test Diagnostics are presented showing information pertaining to the test. The user should consult the Test Diagnostics for warnings – highlighted yellow. An option to move on to Data Analysis is presented - click “Transfer to Data Analysis” when ready.

4.3.4 Profilometry Mode

Profilometry Mode is designed to measure topographical line scans.

To initiate the Profilometry Mode, navigate to **Tools > Profilometry Mode**:

1. The desired scan distance is requested by CORSICA prior to the operation.
2. The crosshead will move down and find the sample reference height with the LVDT. The profilometer will then move across and the user will be asked to locate the profilometer for the scan. Scanning occurs from left to right starting from the position following the location of the profilometer.
3. The profilometer has a range limit of $\pm 200 \mu\text{m}$. If the scan goes beyond this (due to tilt or features in the sample), it will fail.
4. The output is a profile scan and surface roughness values - the surface roughness values are calculated over the central 20% of the scan by fitting a second order polynomial to this data and taking this away from the data. This removes the macro shape and leaves the surface roughness. Issues may be found if the region of interest lies outside this range of the scan or if a second order polynomial is not suitable to remove the macro shape. A .csv file is created on completion with this data.

4.3.5 Profilometer Alignment Check

The profilometer alignment check refers to a check on the symmetry of the profile (x-scan only). If the plot is not visible, it can be activated via **View > Tabs > Profilometer Alignment Check**. Profilometer alignment should not require frequent adjustment. CORSICA will flag alignment issues in the “PLX-Benchtop Status” output of the “Test Diagnostics”, but the user only needs to rectify the alignment if there is persistent misalignment in the spherical part of the indent profile.

In order to correct the profilometer alignment:

1. Move the machine such that the rear can be accessed.
2. Find the small Pozi-drive screwdriver and 8 mm spanner supplied in the small Peli Case, as well as a sample with an indent known to be radially symmetric (the profilometer calibration sample is recommended).
3. Loosen the two screws in the back of the profilometer – they only need to be loosened slightly (1/4 of a turn) such that the spanner is still required to rotate the adjuster. If the profilometer is freely rotating, the screws should be tightened.
4. Navigate to **Tools > Profilometer Alignment** and start the procedure.
5. Allow the machine to take an initial profile of the indent, such that the halves of

the indent can be assessed. The machine will assess the level of misalignment and provide a direction to rotate the adjuster when facing the rear.

6. Use the spanner to rotate the adjuster, taking care not to over rotate, then allow the machine to scan the indent once again. Repeat this operation until there is good agreement of the profile halves, whereupon the screws can be retightened and the profilometer parked.

4.3.6 Change Indenter Tip

When deciding on a tip for indentation, the 1 mm radius tip should be the preferred choice. If the scale of the features or sample size is such that a smaller ball would be more appropriate, the 0.5 mm or 0.25 mm radius tips can be used.

To initiate the Change Indenter Tip procedure, navigate to **Tools > Change Indenter Tip**:

1. Input the radius of the new tip. The PLX-Benchtop is provided with a 0.25 mm, 0.5 mm and a 1 mm radius tip.
2. Remove the installed tip by removing the 3 M3 bolts in the insert with a 2.5 mm Allen key. The insert should fall loose when this is done.
3. Install the new tip by pushing the insert up, ball side down such that the LVDT goes through the hole in the insert. Push the insert up and rotate it until the dowel pin in the insert locates in the housing. With the part in place, screw in the 3 M3 bolts.
4. Once the tip has been swapped, the software will prompt the user to carry out the Machine Set Up operation.
5. On completion, return the insert that has been removed to the supplied box, which will have an ID that matches that of the tip. The tip radius value is given on the small case in the Peli Case that was supplied with the PLX-Benchtop.

For replacement tips, contact Plastometrex at support@plastometrex.com.

4.3.7 Traceability and Metadata

When a test is initiated (indentation or take profile), the user is prompted to fill out material information, located in the “Populate PLXUS data” tab shown in Figure 4.4. Users are encouraged to provide detailed information where possible, and this will be stored along with the test data in PLXUS (see §5). When testing a lot of a particular material, the PLXUS data can be saved and re-loaded in subsequent tests from the Saved Material Database.

Figure 4.4 Metadata Capture in CORSICA.

4.3.8 Indenter Tip Health Monitoring

A tip damage detection algorithm analyses data coming from the profilometer to detect if a tip is damaged. In cases where CORSICA detects potential damage, it will warn the user to contact Plastometrex.

The tip material is a silicon nitride, which is susceptible to brittle failure, particularly when indenting the hardest of metallic materials ($\sigma_y > 3$ GPa). Key things that indicate tip damage are the load displacement curve having a load drop, audible cracking noises, or residue tip material visible around the indent location. Deviations from the expected indent shape may also be seen in the profile data.

If you are presented with a tip damage warning or if you think you have damaged a tip, contact Plastometrex at support@plastometrex.com for more information. The user should understand that ceramics, cermets, glasses etc. should not be tested.

4.3.9 Embedded Knowledge Centre

Included throughout CORSICA are a series of help sheets relating to different parts of the test, analysis and interpretation. These can be accessed through the 'More Info' buttons found in the 'Test Setup Info', 'Test Diagnostics' and 'Results Interpretation' pop ups, and via the help ('?') buttons. Additionally, the Plastometrex Knowledge Base can be accessed through **Help > Knowledge Base**.

5 PLXUS Introduction

PLXUS is Plastometrex's cloud-based digital platform for the collection, curation, and analysis of the materials testing data generated by the PLX-Benchtop, the PLX-HotStage module and the PLX-Portable. It provides centralised storage and archiving of test results, sharing and collaboration tools, and user-friendly features for data discovery, data management, trend identification, and ROI metrics.

PLXUS Archive (Figure 5.1 PLXUS Archive) allows the user to plot, export, and share results from their tests, fault find, and learn with the provided help sheets. Contact your applications engineer to get access to PLXUS.

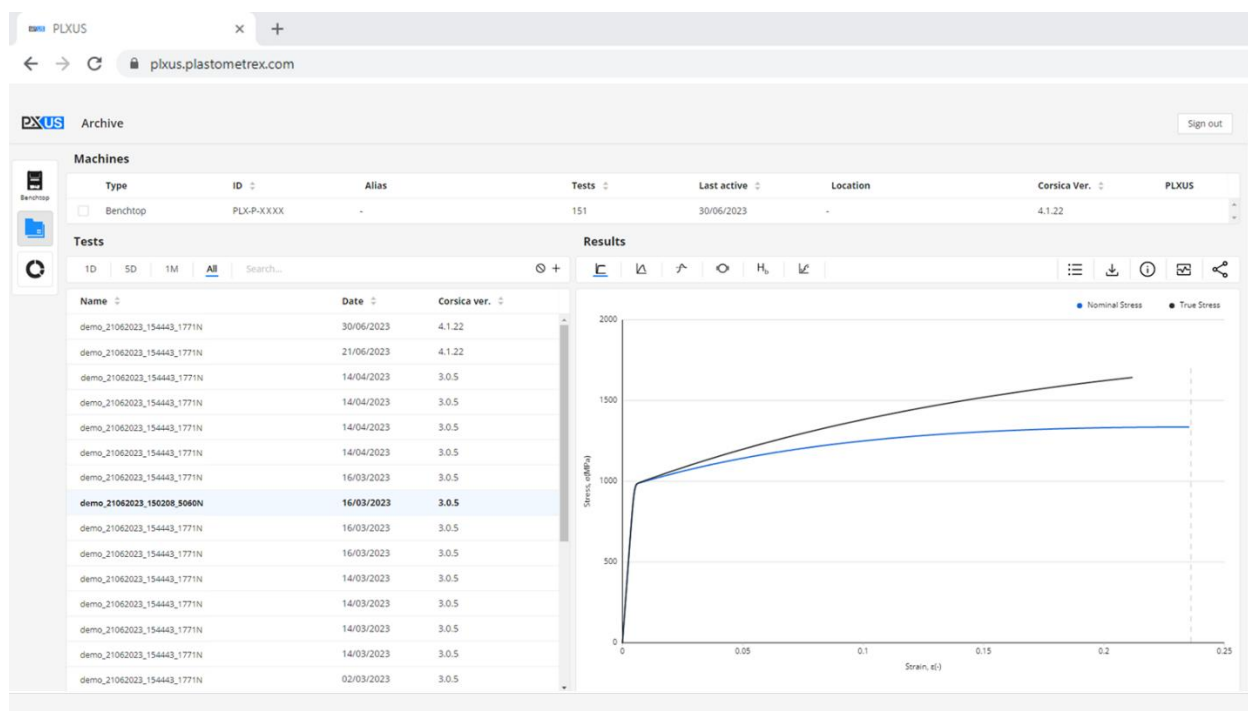


Figure 5.1 PLXUS Archive

6 Sample Requirements

6.1 Sample Dimensions

The minimum and maximum sample dimensions for the two indenter tips that are provided with the PLX-Benchtop are given in Table 6.1.

The minimum sample dimensions relate to the assumption in the finite element modelling that the sample is “semi-infinite”. The dimensions have been set such that this assumption is not breached and apply even if the sample is mounted in plastic. In fact, when approaching the lower limit of lateral dimensions, it may be necessary to mount the sample, see §6.4, and position the LVDT on the mount material to meet the sample positioning criteria in Figure 3.2.

Indenter tip radius (mm)	Min lateral dimensions (mm)	Max lateral dimensions (mm)	Min thickness (mm)	Max thickness (mm)
1	6	150	3	70
0.5	3	150	1.5	70
0.25	1.5	150	0.75	70

Table 6.1 PLX-Benchtop maximum and minimum sample dimensions

The maximum sample dimensions relate to what can fit in the test space. The sample thickness cannot be above 70 mm as a small clearance is required for the profilometer to move beneath the crosshead. Indenting samples beyond the maximum lateral limit is technically possible, provided the sample is well balanced and supported on the central platen.

6.2 Sample Preparation

Samples must be prepared to meet the requirements in Table 3.2 Sample Requirements. These requirements can usually be met using a P1200 grit grind for the 1 and 0.5 mm radius indenter tips and a P2500 for the 0.25 mm indenter tips. The test can tolerate an incline between the support surface and the indented surface of up to 2°. Additionally, the sample should be flat on the scale of an indent (within the lateral dimensions specified in Table 6.1). Where samples have an awkward shape, mounting is an option, covered in §6.4.

The surface roughness adjacent to an indent is measured as part of every PIP test. If the roughness is too high, the user will be notified.

6.3 Effect of Sample Surface

Being an indentation-based technique, PIP will interrogate a near surface region. Thought should therefore be given to the presence of any near-surface layers with different properties to the bulk, such as protective layers, surface damage from machining, or contours in additively manufactured parts. If bulk properties are desired, such layers should therefore be removed - grinding and polishing operations can be used to remove such layers. Care should be taken with soft materials ($\sigma_y < 100$ MPa), where grinding operation can introduce detectable surface damage - a hardened layer that is 20 μm thick could affect the outcome. Prolonged fine scale polishing during the final stages may be advisable with such materials.

6.4 Mounting

The PLX-Benchtop can be used with either mounted or unmounted samples. Mounting may be chosen to facilitate grinding or polishing of small samples, or due to an irregular sample shape. Most mounts should be able to sustain the peak applied loads without becoming damaged in any way. Below are some options for mounting your sample:

1. Not mounted – ensure the sample has two parallel sides (within the 2° incline angle tolerance).
2. Hot mount – For samples that are not affected by temperatures reached during hot mounting ($\sim 200^\circ\text{C}$), this form of mounting is preferable. Try to minimise the depth of the mounting material beneath the specimen as depicted in Figure 6.1.
3. Cold mount – For samples that may be affected by temperatures reached during hot mounting ($\sim 200^\circ\text{C}$), cold mounting is preferable. Try to minimise the depth of the mounting material beneath the specimen as depicted in Figure 6.1.



Figure 6.1 Schematic of the ideal mounting arrangement, with the material below the sample minimised.

When mounted samples are used, the LVDT (used to measure displacement during a test - see §3.3) should be placed on the metallic sample if possible. The displacement data is important for ensuring that the indentation depth is appropriate. Given the compliance of polymeric mount material is somewhat greater than metallic sample material, it is possible for significant elastic recovery if the LVDT is placed on the mount material. Therefore, users should try to avoid placing the LVDT on the mount material where possible.

6.5 Indentation near the Edge of a Sample

Indentation should not be carried out very close to a free lateral surface (an “edge”) - whether this is actually free or is embedded in a more compliant mounting medium. If such an edge is sufficiently close to the plastic deformation field in the sample, then the radial symmetry of the modelling could be lost. Therefore, indents should not be made closer than about 3 mm from an edge for testing with the 1 mm radius indenter tip, 1.5 mm from a free edge for testing with the 0.5 mm radius indenter tip, and 0.75 mm from a free edge for testing with the 0.25 mm radius indenter tip. Failure to do so will result in additional error.

6.6 Indentation near another Indent

Indentation should not be carried out very close to another indent. If too close, the plastic deformation fields from neighbouring indents will overlap and the radial symmetry of the modelling could be lost. Therefore, indents should not be made closer than about 5 mm from another indent for testing with a 1 mm radius indenter tip, 2.5 mm from another indent for testing with a 0.5 mm radius indenter tip, and 1.25 mm from another indent for testing with a 0.25 mm radius indenter tip. Failure to do so will result in additional error.

6.7 Material Type

PIP is oriented towards measuring the stress-strain curve of metallic materials.

6.7.1 Ceramics

Ceramics are not suitable for testing with PIP. With these materials, there is little or no plastic deformation before fracture. The “strength” of such materials, which is often sensitive to the prior presence of flaws, cannot be predicted using a plasticity-based approach and testing these materials is likely to damage the indenter tip.

6.7.2 Polymers

Polymeric materials, and polymer-based composites are not suitable for testing with PIP. They do often exhibit extensive plastic deformation, but their behaviour is often markedly viscoelastic - i.e. there is a strong time dependence to their mechanical response.

6.7.3 Metal-Matrix Composites

Metal matrix composites (MMCs) can be tested, although damage to the tip is more likely if there is a large proportion of a hard phase or if these particles are large (100 μm +). MMCs may also exhibit strong anisotropy and inhomogeneity. Cermets, which comprise ceramic particles bonded together with a low volume fraction of a metallic phase, could be regarded as a special type of MMC, but they are too hard for PIP, and should not be tested.

6.8 Material Exceptions

As PIP is fundamentally a different measurement technique from tensile testing, there are some cases where comparisons cannot be readily made. These are listed below, and links are provided to articles providing further detail.

Characteristic	Comment	Link
Anisotropy	The material displays directionally dependent mechanical properties. PIP creates strains in all three principal directions and will provide a directionally averaged response.	Link
Inhomogeneity	Mechanical properties vary within sample volume. PIP indents a small volume of material while tensile testing will provide an average response over the gauge volume. This can allow PIP to map properties across a sample.	Link
Grain size	Grain size is large compared with the indentation volume. PIP aims to sample >20 grains. If this is not achieved, results will differ from those obtained through tensile testing.	Link
Porosity	Porosity observed in sample. PIP results will differ from tensile if porosity is above ~1%.	Link
Dimensions	PIP requires testing to be performed on samples that have minimum dimensions.	Link
Fracture	Sample fractures during indentation, or fractures prior to necking within tensile test. In this situation, PIP results will differ from comparative tensile testing.	Link
Phase transformation	Sample undergoes deformation induced phase transformation. In this situation, PIP results will differ from tensile testing.	Link
Tension-compression asymmetry	Sample exhibits tension-compression asymmetry. In this situation, PIP results will differ from tensile testing.	Link
Lüders banding	Sample exhibits Lüders band behaviour. In this situation, PIP results will differ from tensile testing.	Link
Strain rate	Sample exhibits a dependence on strain rate. PIP does not create a uniform strain during indentation, so a defined strain rate is not achieved. Indentation speed can be varied to create situation nearer to quasi-static.	Link

7 Data Analysis - Background Information

7.1 Plasticity Description - Voce

The key function of CORSICA is to extract the plasticity characteristics of the material from the experimental outcome (residual indent profile) using the PIP technique. These characteristics are expressed as a true stress v. true strain relationship, in the form of an analytical expression - i.e. a constitutive law. Several such laws have been proposed, but just a single one is used in CORSICA. This is the Voce expression, which may be written as:

$$(7.1) \quad \sigma = \sigma_s - (\sigma_s - \sigma_y) \exp\left(\frac{-\epsilon}{\epsilon_0}\right)$$

where σ is the (true) strain, stress level and σ_y is the yield stress σ_s is a saturation (flow) stress level is a characteristic strain (for the approach of the stress to its saturation level). After extensive experimentation, it has been found that this law captures the plasticity characteristics most effectively for most metals. The software will then converge on the set of parameter values (σ_y , σ_s and ϵ_0) corresponding to the stress-strain curve that, when employed to simulate the indentation process, gives the best fit with the experimental (residual indent profile) data.

7.2 Elastic Constants

The elastic constants of the material are needed as input data for the analysis. For an isotropic material, only two constants need to be specified to fully define the elastic behaviour. These depend on the predominant type of atom present and are more or less independent of details of alloy composition and microstructure. For example, all ferrous alloys have a Young's modulus (stiffness) value of about 200 GPa, at least to a precision of about $\pm 15\%$. For the purposes of the analysis, elastic constants are not required to a higher accuracy than this. A second elastic constant is required in order to specify fully the elastic behaviour (of an isotropic material). The one used here is the Poisson ratio. Virtually all metals have a value in the range 0.2-0.4. Furthermore, the effect of changing the value is very small when analysing the indentation process. A value of 0.33 is therefore used universally.

The Young's moduli of metals, however, do vary over quite a large range (~20-400 GPa), and there is some sensitivity to its value, so it has to be specified for the (base) metal concerned. Currently, a choice must be made using the dropdown menu. The values, and the types of (base) metal for which they are appropriate, are listed in Table 7.1. The values currently available cover most metals of interest, although the set can be expanded in due course.

Currently available in CORISCA		Not currently available in CORSICA	
Young's modulus ($\pm 15\%$)	Base metal	Young's modulus ($\pm 15\%$)	Base metal
70	Aluminium	20	Lead
	Silver		
	Gold		
115	Copper	50	Magnesium, Tin
	Niobium		
	Palladium		
	Titanium		
	Vanadium		
	Zinc		
	Zirconium		
160	Invar	300	Molybdenum
200	Chromium		
	Cobalt		
	Iron		
	Manganese		
	Nickel		
	Platinum		
	Tantalum		
400	Uranium		
	Tungsten		

Table 7.1 Approximate Young's modulus values for a range of base metals

7.3 Finite Element Method (FEM)

The PIP methodology uses FEM modelling, a powerful numerical method that can be used to analyse complex physical phenomena that cannot be analysed using analytical expressions. The FEM divides a large system into small parts, called finite elements. The partial differential equations that define the physics of the problem can then be solved in each of the finite elements, using numerical methods. This allows complex processes to be simulated for a defined set of input parameters and boundary conditions. In the inverse analysis procedure, the FEM can be used to determine these input parameters via an iterative refinement procedure. PIP employs this method to determine the (unknown)

plasticity parameters of metallic materials.

The model in PIP uses the Voce Plasticity Law to define how the material behaves plastically.

7.4 Converting from True to Nominal Tensile

The standard outcome of a tensile test is a plot of the nominal stress against the nominal strain. The former is the force divided by the original sectional area and the latter is the change in length (along the loading direction) divided by the original length. The true stress acting is the force divided by the current sectional area. After a finite (plastic) strain, under tensile loading, this area is less than the original area, as a result of the lateral contraction needed to conserve volume, so that the true stress is greater than the nominal stress. In practice, it is quite common to present only the nominal plot, and several common procedures for extraction of key parameters are based only on inspection of such curves. To convert from the true form of the stress-strain curve to the tensile nominal, the following analytical curves have been used, noting that these equations are appropriate up to the UTS.

$$(7.2) \quad \sigma_N = \frac{\sigma_T}{(1 + \epsilon_N)}$$

$$(7.3) \quad \epsilon_N = \exp(\epsilon_T) - 1$$

Where σ_N is the nominal stress, ϵ_N is the nominal strain, σ_T is the true stress and ϵ_T is the true strain.

8 Troubleshooting and Error Identification

8.1 How do I identify an error?

When an error occurs, the machine will stop, a dialogue box will appear, and the LED strip will flash red. The error status of the machine will remain until the error is cleared via the dialogue box in the CORSICA software. The dialogue box will contain additional information about the error included an overview of the error as well as a potential fix, an error code and a link.

8.2 What do I do when an error occurs?

Consult the message provided in the dialogue box. This should allow you to resolve the issue and continue. If the advice does not prove useful, or if particular errors persist, contact Plastometrex at support@plastometrex.com

8.3 Why is the machine not moving at all?

The checklist below should be completed to resolve the issue:

- Check that power is going to the machine and that the machine is switched on – fans in the top casing should be audible.
- Check that the computer is connected (via both USB and Ethernet) to the PLX-Benchtop.
- Check that the emergency stop is not pressed in. If it is, twist to release and restart CORSICA.
- Check if you are at the top/bottom of the range of the crosshead, such that the limit switches are engaged. Move the crosshead towards the opposite limit using the buttons in the GUI.
- Check for comment “Failed to connect to dryve D1” in the logs, meaning the motor controller is not communicating with the PC. This may require an update to the Ethernet port settings (instructions [here](#)).

If any of the below occur, try restarting the machine and software. If they persist, contact Plastometrex at support@plastometrex.com

- The DAQ is not recognised. If this is the case, the load and LVDT readings on the GUI screen will read (-).

- The profilometer is not reading, which will result in the message “No profilometer reading” in the status panel.
- Issue with the profilometer stages connection, which will result in the message “No stage x reading” in the status panel.

8.4 The crosshead will only move at the slowest speeds, why is this?

- The speed selector on the GUI is not set to the desired speed.
- The load cell may need zeroing. This could be due to drift over time, or the placement of a particularly heavy sample on the sample platform. Confirm that the crosshead is not applying additional load to the sample and/or load cell and set the load cell to zero with the balance button.
- The LVDT could be reading a value which is not suitable for idle position. This may be due to drifting, or perhaps the LVDT has snagged following an indent and not returned to its resting position (this will involve an LVDT reading larger than 50 μm). Apply a gentle lateral load to the LVDT tip to return it to its idle position and then balance the LVDT reading.
- The profilometer may be reading a signal when it should not be. Visually inspect that the area is clear. If it is, contact Plastometrex at support@plastometrex.com
- If you are bringing the crosshead down manually so that the LVDT and/or indenter tip contacts a sample (not recommended), it is important that neither are balanced midway through this operation.

8.5 Why is “devices are not ready” being displayed?

In the bottom left-hand corner, there is an icon, which turns green and reads “Devices Ready” when booting up is completed successfully. If the “Devices Not Ready” icon persists, turn off power to the machine and disconnect the USB cable. Reconnect and return power and try the software again. If this does not work, try removing power, re-starting the PC and try again. If the problem persists after trying this, contact Plastometrex at support@plastometrex.com

8.6 The profilometer is giving a reading when parked

This is possible following a knock to the profilometer tip. It is important that some care is taken with regards to the tip. This will manifest itself as a warning in the bottom right-hand corner and will limit the speed of the crosshead. Contact Plastometrex if this problem is

encountered.

8.7 Error codes

The error codes attempt to provide the user with an idea of what has caused the error and how to prevent it in future or circumvent it for the time being. In each case, an error code and link are given. These may be useful for Plastometrex support so do make a note if a problem persists.

8.8 Error not covered here

In the event that no information on the error is provided here and you are unable to solve it or move on with testing, contact Plastometrex at: support@plastometrex.com.

9 Contact Details

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Information, diagrams and instructions for the repair of the machine are available upon request, by contacting support@plastometrex.com