

Annex 2C: Zwick/Roell Kappa 100DS user manual

As a result of the active participation on the creep experimental campaign by the PhD. candidate, expertise on the use and exploitation of the features of the creep machine Z/R Kappa 100 DS was acquired. The numerous setbacks related to ceramic inserts breakage, machine components acquisition and communication with manufacturer technicians turned into opportunities to further improve the knowledge of those operating the creep machine. In this context, the PhD. candidate in cooperation with M&S technicians and supervisors, wrote a comprehensive user manual where the correct creep testing procedure is offered. The document, shared in the following pages, contains advices and recommendations gathered alongside this research.

An additional event that can hamper the progress of a creep test is that of an electrical power shortage. If the creep machine loses power, the furnace will shut down and the crossheads will remain locked in the last position. With time, and even if the power comes back, the machine will not resume the test. The danger of the situation described herein resides in the incremental thermal stresses that will appear as the specimen cools down to room temperature. The risks associated with such an event are described in the last document attached on this annex.

In-house user manual | Zwick/Roell Kappa 100DS

Instructions to safely conduct a creep test in the machine

PhD. Student:	Carlos Rojas Ulloa	ce.rojasulloa@uliege.be	☎	+32 4 551 12 006
PhD. Supervisor:	Anne Marie Habraken	anne.habraken@uliege.be	☎	+32 4 366 94 30
Co-Supervisor:	Laurent Duchêne	l.duchene@uliege.be		
Lead technician:	Mario Bustos H.	m.bhermosilla@uliege.be		

Contents

This document provides the instructions and sequence of steps to conduct a creep test on the creep testing machine Zwick/Roell Kappa 100 DS, property of the Materials & Structures laboratory (M&S), University of Liège (ULiège). It is written as a result of a training session provided by Zwick/Roell technician Mr. Gerhard Karlin during 18-19/12/2023, and the experience gathered during the extensive experimental creep campaign in the context of the PhD. project of Carlos Rojas Ulloa. The instructions provided herein have been further optimized after the M&S technician in charge of the creep machine, Mr. Mario Bustos Hermosilla.

Acronyms

AMH	Anne Marie Habraken	mcr	Minimum creep rate
CRU	Carlos Rojas Ulloa	M&S	Materials & Structured lab.
CV	Carl Vroomen, head of (M&S lab)	LVDT	Linear variable differential transducer
G2G	Grip-to-grip	ttr	time-to-rupture
MBH	Mario Bustos Hermosilla	Z/R	Zwick/Roell

List of contents

Overview	3
Machine components and sensors.....	3
Peripheric components and control unit.....	7
System on/off procedure	9
Sample preparation	9
Experimental methodology	11
1. Test preparation.....	12
1.1. Test programming.....	12
1.1.1. Stay onto the correct configuration file.....	13
1.1.2. Configuration of testing system.....	15
1.1.3. Test configuration.....	19
1.2. Specimen mounting	31
1.2.1. Crosshead ranging	34
1.2.2. Thermocouple attachment.....	35
1.2.3. Grip-to-Grip distance.....	36
1.1.1. Extensometer mounting.....	36

Overview

The methodology presented in this document is substantiated on the training sessions given by certified technicians from Z/R in two different instances in combination with the experience from the M&S technician in charge of the creep machine, Mr. Mario Bustos Hermosilla (MBH). It is organized to provide the reader with a clear step-by-step set of instructions addressing machine manipulation, built-in software programming and data acquisition.

- Important security and safety tips are highlighted in yellow.

This overview section deals firstly with the description of the machine, machine components, sensors, and all peripheric components involved in the execution of a test. A list of basic security tips in relation to machine operation and specimen manufacturing is later provided.

Machine components and sensors

Our creep machine is suited with room- and high-temperature testing components. High-temperature creep testing capabilities are mainly limited by the combination of these components. Ascertaining the maximum admissible thermal and mechanical loadings with respect to the intended testing time in each machine component is imperative upon test planification. To this end, the technical specifications and main characteristics of our machine and the main components (furnace, load cell, extensometer, and the pulling rods) are listed hereafter.

Machine: Kappa 100 DS

With the objective of conducting reliable high-temperature creep tests, the MSM team in ULiège acquired a creep machine model Kappa 100 DS from the Austrian company Zwick/Roell (Z/R). It is intended for high-temperature creep testing. Room temperature testing equipment is available; however such tests are considered inappropriate due to the machine loading limitations and concerns about the extensometer components being unsuitable to withstand the impact of such a test. Therefore, the use of the extensometer during high-impact (cyclic, fatigue, tensile,...) tests is not recommended. Furthermore, strain-controlled tests (e.g., relaxation) cannot be conducted with the extensometer. In such a scenario, the crosshead must be used.

The most important technical specifications for the machine are provided in Table 1.

Furnace: MP00850

Acquired together with the creep machine, the Z/R MP00850 furnace is engineered for creep testing. It is a resistance-based furnace and combines high thermal inertia with excellent temperature control during long tests. The main technical characteristics of the furnace are provided in Table 2. The maximum heating rate advised by Z/R in function of the temperature of the furnace is provided in Table 3.

Load cells: 100 kN & 10 kN

The load cell of the machine is the device in charge of constantly monitoring the axial force. The machine was initially acquired with a 100 kN load cell, in accordance with the maximum load capacity of the machine (see Table 1). This load cell provides reliable force measurements (1% error) down to 200 N. This proved to be insufficient for the purpose of the PhD. project of CRU, where creep tests involved forces down to 100 N. A new 10 kN load cell was therefore acquired, rated with 1% error force measurements down to 20 N. The main technical characteristics of both load cells are summarized in Table 4.

Table 1: Summary of main characteristics of creep machine Z/R Kappa 100 DS.

Characteristic	Capacity / magnitude / technical description	Photograph
Load capacity	100 kN	
Test area-depth	unlimited	
Test area-width between drive screws	610 mm	
Test area-height	max. 1350 mm	
Crosshead strokes	1350 mm	
Lateral support of moving crosshead	Precision sliding bearing on four chromium plated columns (40 mm diameter).	
Test speed range	0.001 mm/h to 100 mm/min	
Return speed	100 mm/min	
Crosshead speed accuracy	± 0.1% of setting (no load or constant load averaged over 10mm or 5 s)	
Return stroke-encoder	0.068 mm	
Frame Dimensions	860×655×2310 mm ³ (width×depth×height)	
Weight	840 kg	
Power requirements	230 VAC, 1kVA	

Table 2: Summary of the main characteristics of the furnace used in combination with the creep machine.

Characteristic	Technical specifications	Photograph
Furnace model	MP00850	
Maximum furnace temperature	1200°C	
Maximum specimen temperature	1150°C	
Maximum heating rate*	Up to 30 K/min	
Cooling rate	Natural cooling	
Connection flange	60 mm	

*: limited by the current temperature of the furnace, see Table 3.

Table 3: Maximum heating rate achievable by the Z/R MP00850 furnace according to the manufacturer.

Temperature (°C)	Max. heating rate (K/min)	Temperature (°C)	Max. heating rate (K/min)
100	3	700	15
150	3	750	17
200	3	800	20
250	3	850	20
300	5	900	25
350	5	950	25
400	6	1000	30
450	8	1050	30
500	10	1100	30
550	12	1150	30
600	12	1200	30
650	15		

Table 4: Summary of the main technical characteristics of the available load cells.

100 kN load cell		Photograph
Load cell model	Xforce-K 100kN (item N° 318932)	
Nominal force	100kN	
Accuracy Class* 1	200N – 100kN	
Accuracy Class* 0.5	100N– 100kN	
Installation height	106 mm	
Connection flange	60 mm	
10 kN load cell		
Load cell model	Xforce-K 10kN (item N° 318932)	
Nominal force	10kN	
Minimum resolution	0.034N (297×10 ³ steps)	
Accuracy Class* 1	20N – 10kN	
Accuracy Class* 0.5	100N– 10kN	
Connection flange	60 mm	
Temperature influence	at 0-point: ±0.001% per K at measured value: ±0.004% per K	

*: according to the manufacturer, class-accuracy is equivalent to the %-error in the measurement.

Load strings or pulling rods

Upon testing, the specimen is mounted into the machine in connection with pulling rods above and below the specimen. In general, 2 are required for cylindrical specimen (1 above, connecting to the crosshead, and 1 below, connecting to the load cell, see Figure 2) whereas 3 are required for flat specimens (1 above, 2 below). This is mainly due to specimen length.

The load strings are manufactured from a corrosion-resistant Ni-alloy, and the alignment is engineered following ASTM E1012. They are rated to withstand temperatures of up to 1200°C. No maximum service time in function of the axial load or temperature is indicated.

High-temperature specimen adapters

The connection between the pulling rods and the specimens is achieved using two high temperature adapters specific to the specimen geometry. These are manufactured from MAR-M 246 corrosion resistant Ni-alloy. The maximum admissible thermal and mechanical loadings these components can withstand is given by the manufacturer in relation to the length of the creep test. The maximum applicable load according to the test temperature and time-length is given per each set of adapters (for specimens D06, D10 and P58, see Table 9) in Table 5.

Displacement transducer: Linear extensometer

To allow reliable recording of axial displacements during high temperature testing while inside the furnace, a specialized extensometer is used. It has long ceramic arms that connect the linear variable differential transducers (LVDTs) to the specimen gauge length section. The extensometer is attached to the specimen by a conjunction of ceramic pieces that match the geometry of the specimen collar. The main technical characteristics of the extensometer are given in Table 6. A photograph showing the extensometer, LVDTs and specimen attachment is presented in Figure 1.

Table 5: Manufacturer instructions on the maximum admissible axial force that can be applied on the high-temperature adapters according to the temperature and time span.

	Temperature (°C)	Maximum axial force (kN) according to creep test duration		
		10 hours	100 hours	1000 hours
D06 adapters	600	56.3	34.8	32.7
	700	45.0	27.4	23.3
	800	35.3	19.2	14.3
	900	24.0	11.5	6.9
	1000	9.7	3.2	2.4
D10 adapters	600	110.0	85.0	80.0
	700	88.0	67.0	57.0
	800	69.0	47.0	35.0
	900	47.0	28.0	17.0
	1000	19.0	8.0	6.0
P58 adapters	20	8	8	8
	800	8	4.9	4
	900	7.2	2.8	1.9
	1000	4.7	1.3	0.9

Table 6: Main technical characteristics of our high temperature extensometer.

Characteristic	Technical specifications
Material	Ceramic (Main structure of Al_2O_3 ; replaceable inserts of ZrO_2)
Maximum temperature	1200°C
Resolution	< 1 μm
Maximum displacement	50 mm (regulated by adjusting the LVDT screws, see Figure 1)

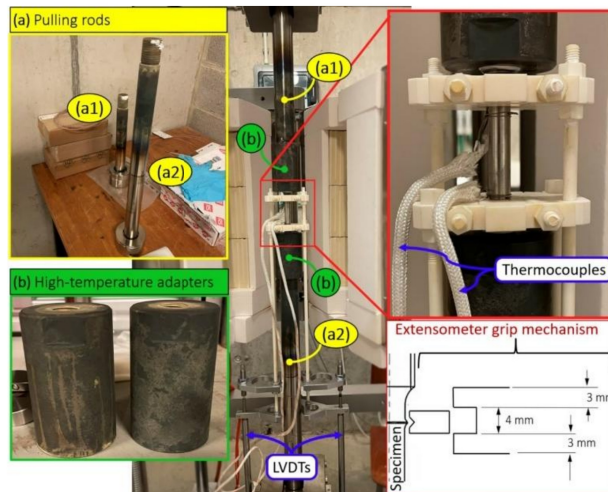


Figure 1: Machine layout with a D10 specimen ready for testing. Essential testing components such as pulling rods (a), high temperature specimen adapters (b) and extensometer are shown in detail side frames.

Peripheral components and control unit

The creep test equipment consists of three main units: the test control unit (named “*testControl II*”), the Furnace control unit (named with its model id. “*ME44-186 V3.71*”), and a desktop computer fully dedicated to work as a machine user interface. These are numbered as 1 (red), 2 (green) and 3 (blue). The number and respective colors are given in laboratory layout of Figure 2.

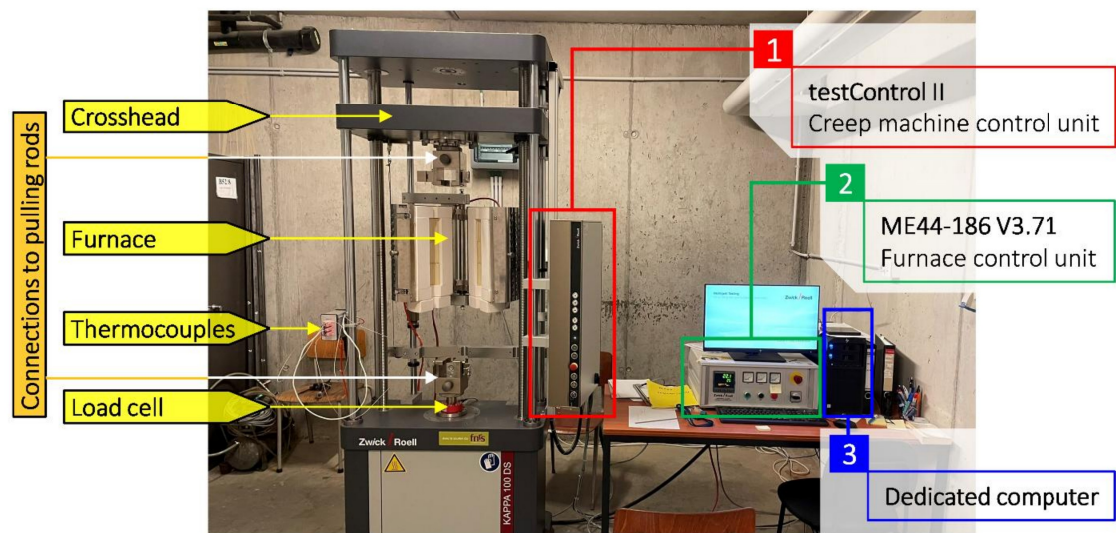
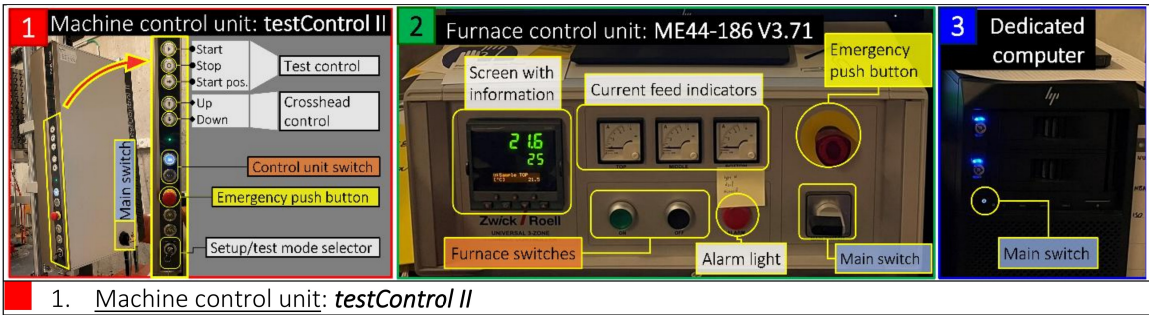


Figure 2: Photograph of the layout of the creep machine Kappa 100 DS at M&S laboratory in ULiège. A list of some important fixed machine parts and components is given at left, whereas the two main peripheral components and the dedicated interface desktop computer are listed at right.

The operation of the peripheral components during testing is controlled digitally via the user interface installed in the dedicated desktop computer (3 in Figure 2). Manual inputs are, however, required in exceptional circumstances. To this end, the user must be familiarized with the buttons of each peripheral component. These are described in detail in Table 7.

Table 7: Description of main creep machine peripheral components allowing control of the creep machine.



It is the control unit in charge of the mechanical components of the creep machine: crosshead movement, displacement transducers (i.e., linear variable differential transformers, LVDTs), load cell, and the furnace control unit (1). It also serves as a means of communication between (3) and all creep machine components mentioned hereabove. A test is loaded into the *testControl II* unit as a series of instructions (a process similar to that of programming a microcontroller). Nevertheless, it enables the user to introduce the following manual inputs:

- **Main Switch:** It is the master switch that controls the energy input to the *testControl II* unit.
- **Test control:** Once a test is loaded into the *testControl II* unit, the user may start the test using these three buttons. While the first two are self/explanatory, the latter (“Start Pos.”) is used to reset the position of the crosshead to its initial position. The initial position must be recorded before the test, as explained later in section Crosshead ranging.
- **Crosshead control:** These push buttons allow the user to control the position of the crosshead. Manual control of the crosshead is required when a specimen is mounted, dismounted, or when adjusting the “Start Pos.” (start position) of the crosshead. Instructions for such procedures are given later in section 1.2.
- **Control unit switch:** These push buttons are intended to turn on/off the device after the current supply through the Main switch is activated. Communication with the device can be established while off (i.e., sensors will be operational), but no output nor input may be registered.
- **Setup/test mode selector:** The programming of the creep machine is organized into these two main modes. **Setup** mode is intended to modify parameters related to peripheral components and sensors, whereas **test** mode is intended for the programming of a specific test. More details on the programming procedures in relation to these two modes is provided in section 1.

2. Furnace control unit: *ME44-186 V3.71*

It connects the furnace and thermocouples information to the *testControl II* unit (1). It is also the main power supply to the furnace. During operation, it provides the user with in-situ information of the furnace working state: the objective and current temperatures are displayed at the screen; the electric amperage of the three heating devices of the furnace (i.e., resistors top, middle and bottom) are given in the respective current feed indicators; and an alarm light will light-up in case of emergency. It allows for certain user-defined inputs:

- **Screen with information:** The push buttons located at the bottom edge of the screen allow the user to select a specific temperature to display.
- **Main switch:** It is the master switch that controls the energy input to the device.
- **Furnace switches:** These push buttons are on/off switches controlling the electric supply towards the furnace resistors. Communication with the device can be established while in off mode (i.e., sensors will remain operational), but no input/output may be registered. **To avoid accidents, this device switches shall remain off; they should be activated exclusively during testing.**
- **Alarm light:** Besides the manual input mentioned hereabove, this device includes a built-in alarm light indicator. It is automatically turned on in situations where anomalous behaviors are detected (e.g., when temperature values are found outside physical meaning, indicating a possible thermocouple failure). The activation of this light is accompanied by an automatic furnace shutdown and an alarm message on the computer screen (3), which requires user input.

3. Dedicated computer

This computer is intended exclusively to be used as the interface for the creep machine control unit (1). It is disconnected from the internet and runs Windows 10 with a standard configuration. Control and communication to the machine and all its peripheral components is established by means of the software *testXpert III*. Developed by Z/R, it is used as a graphical user interface to load tests, program tests, control

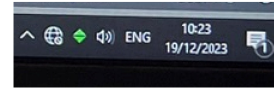
the machine and all its peripheral components, and read and export test results. The access to the software is given by a direct access file located at the very center of the desktop screen of the computer.

System on/off procedure

The entire system must be turned on before making any inputs to any of the system components. The use of any of the 3 components mentioned hereabove without ascertaining the effective communication between *testControl II* and the computer (1 and 3 in Figure 2) is completely unadvised. The recommended sequence of steps to turn the system ON is described in Table 8.

Table 8: Sequence of steps necessary to turn on the system and assure the good communication between *testControl II* and the computer.

STEP	Description
1	Turn ON the main switches of the components following this precise order: (1) – Machine control unit (2) – Furnace control unit (3) – Computer
...Once the session in the computer has started...	
2	Open the software TestXpert III located in the middle-section of the screen desktop. The onset of two green arrows appearing in the lower right corner of the screen indicates that communication with <i>testControl II</i> is in effect.



Once communication is established, the user should first open a machine configuration file before taking any action. Opening the correct *.ZP2 file will allow the software to recognize the sensors currently connected to the *testControl II*. This procedure is specified in section 1.1.1 as part of the test programming procedure.

Sample preparation

Factors such as geometrical defects or material inhomogeneity can greatly affect the viscoplastic deformation of materials, often exhibiting non-uniaxial deformations. Inhomogeneous deformations of this type may generate a bending moment in the specimen that must be absorbed by the extensometer ceramic inserts: hard, brittle, and expensive machine components. Overall, this situation endangers the integrity of the entire machine and the reliability of the experiment. To avoid this situation, it is imperative that all tested specimens are manufactured following the Z/R geometrical constraints. Given our currently owned machine components and spare parts, the creep machine at M&S lab at ULiège allows for three types of geometries: Flat specimens of 5×8 mm² cross section, and round cylindrical specimens of 6 and 10 mm diameter. These are described in Table 9 alongside with the directory in the MSM team server where the Z/R planimetry documents are allocated.

Table 9: description of the 3 creep specimen geometries allowed to be tested with this creep machine, alongside the directory where the planimetry for fabricating such geometries can be found.

Geometry	Specimen description	Document directory in MSM team server:
P58	5×8 mm ² section, flat	... \Drever 2018 et creep\FRIA_PhD\02_800H_research\... ... \ExperimentalCampaign\Geometries\P58.pdf

D06	6 mm diameter, round	...\ExperimentalCampaign\Geometries\D06.pdf
D10	10 mm diameter, round	...\ExperimentalCampaign\Geometries\D10.pdf

Geometrical characteristics such as diameter (for round specimens) in-between and outside the collars, collar shape, collar-to-collar length (i.e., gauge length) and threading must be thoroughly checked after receiving the specimen from the manufacturer and before mounting into the machine. It is hereby recommended to corroborate the correct thread manufacturing of cylindrical specimens by screwing them manually into the corresponding female thread grip. An illustration of the process is provided in Figure 3.



Figure 3: Illustration of good fit of cylindrical D10 specimen with corresponding female threads of compatible high-temperature adapters confirming a correct thread manufacturing. **Note:** the use of thermal paste (as seen here) is only for high temperature testing. In case of a trial thread test (to verify thread quality), do simple manual threading with no thermal paste involved.

Special case: test CT012 of PhD. project of CRU.

Context: Creep test on Incoloy 800H specimen D10 at high temperature & low stress.

Situation: The test was performed until rupture, lasting around 60 days. Such long term high-temperature exposure led to the specimen to tighten onto the high temperature adapter threads. The fracture of the specimen (right in the middle-section) also meant that it was not possible to grip the pieces effectively to unscrew them from the female threads:

Solution: Cut the sections of interest (gauge length) with a saw. Then, remove the rest of the specimen (thread section still stuck on the adapters) by soldering a long metal rod to generate higher torque during unscrew.

Advice: In cases where long-term high temperature exposure is foreseen (e.g., +30 days), threading the entire specimen (as seen in Figure 3) should be avoided. Instead, leave a small number of threads outside of the adapters, thus easing the unmount procedure.

It is also important to remind that high temperature exposure of materials can potentially lead to the incineration of any substance or residue remaining, for instance, from the machining process of the

specimen (e.g., oil, grease, or similar fluids...). This has been observed as a dark smoke pouring out of the furnace chamber, which can potentially interact with the smoke detector installed in the room and lead at the very least to a test interruption. Careful cleaning of the specimen before mounting it into the machine is therefore imperative.

Experimental methodology

The methodology to conduct a test is organized into five different stages. The activities of each stage and its ordered sequence are presented in the form of a flowchart in Figure 4. Stage 1 contains all activities related to the preparation of the creep test; both activities 1.1. and 1.2. can be conducted in parallel with no specific or recommended order. Stage 2 entails the execution of the test previously programmed in Stage 1. The finalization of the test is illustrated in Stage 3, pointing at all possible outcomes. Finally, the experiment data is recovered at stage 4.

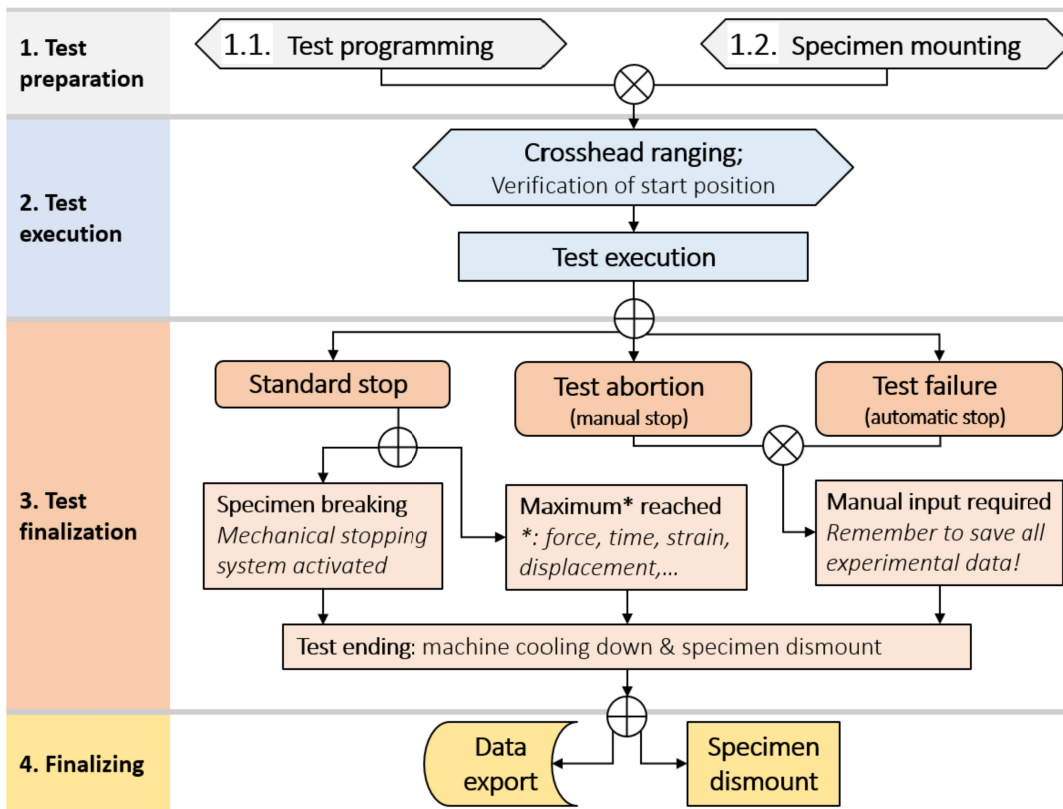


Figure 4: Flowchart describing the general test execution methodology on our creep machine.

The step-by-step procedure illustrated for Stage 1 in Figure 4 is explained in detail within section 1 of this report. The section and subsections are numbered according to the flowchart.

1. Test preparation

Before taking any action, one must first ascertain the type of test and loadings. According to the manufacturer, our creep machine Z/R Kappa 100 DS with extensometer mounted is suited for two types of tests: creep tests and low-frequency stress or temperature-controlled creep fatigue tests. For the latter, the thermal cycles are limited to a maximum heating/cooling rate of 2.2 °C/min). In any case, the user must verify that the objective thermal and mechanical loadings of the test are found within the admissible ranges of the creep machine and its components as advised by Z/R. The capabilities and limitations of the machine and each of the components involved in testing are listed in section Machine components and sensors.

After verifying the feasibility of the test, the user must also have a clear depiction of the expected behavior of the material during testing, substantiated if possible by reliable literature or previous results. With this information, the expected time-to-rupture (ttr) and that the maximum expected axial deformation must be verified. For instance, test time limitations according to the ttr and the specimen geometry indicated by the manufacturer are provided in Table 5. The user must also be aware that **the maximum extensometer gauge length is 50 mm** (see Table 6).

After addressing the aspects mentioned above, the user may start Stage 1 of the flowchart of Figure 4: preparing the test in the machine. This stage has been divided into two main tasks: test programming (section 1.1) and specimen mounting (section 1.2). The user may choose which to perform first, however certain test programming parameters can only be introduced after the specimen is mounted.

1.1. Test programming

The Z/R software *testXpert III* allows the user to introduce and load the set of instructions necessary for the machine to run the test. The programming methodology follows a block sequence logic. A block is defined as an individual set of instructions where an objective thermal or mechanical loading is reached and held over a defined time. Upon finalizing this holding time, the instructions of the next block in the sequence are executed.

Let us propose a simple example where a creep test is conducted at a temperature T_1 and a constant axial load F_1 . According to standard ISO-204, the test must be performed following this sequence of steps (not blocks):

- (1) Reach a pre-load equivalent to 10% of the total axial load during test. Maintain until step (4). The preload configuration is introduced by the user outside the context of the block configuration, and is thus not part of the block test methodology.
- (2) Heat up the specimen until the objective temperature is reached.
- (3) Hold the objective temperature for 60 minutes.
- (4) Increase the axial load from preload until F_1 is reached.
- (5) The test is hereafter considered begun. Axial force, displacement and temperature recordings within this block are the essential part of the test output data. T_1 and F_1 are held constant until user-defined maximum (i.e., displacement or test time) is reached, or until the specimen breaks.

To conduct such a test, the sequence (1) to (5) is efficiently grouped into three different blocks A, B and C. These stages and block subdivision is illustrated on two separate temperature and axial force history plots in Figure 5a and b respectively. This programming logic must later be applied to write the test instructions within the software. This procedure is explained in detail in section CE05 of 1.1.3.

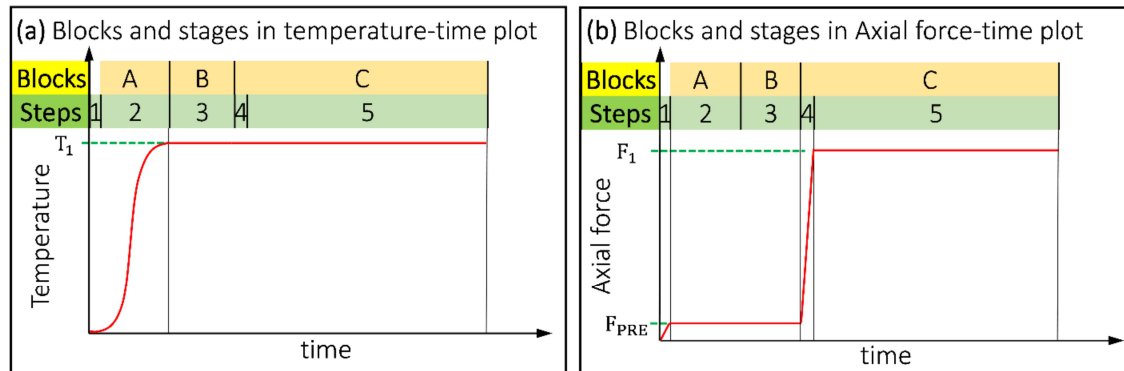
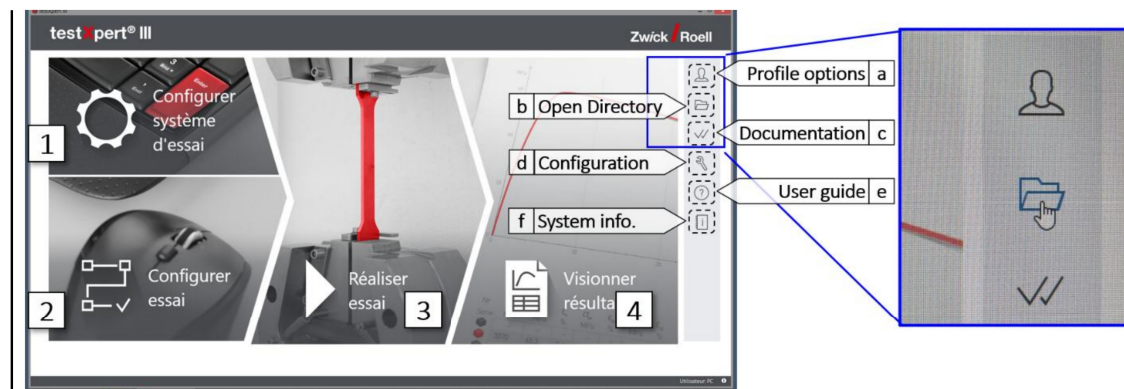


Figure 5: Representation of blocks (following the programming logic for *testXpert III*) and steps (according to ISO-204) subdivision on illustrative temperature (a) and axial force (b) history plots belonging to a creep test.

1.1.1. Stay onto the correct configuration file

The very first step is to access the *testXpert III* software. To do this, the entire system must be turned on following the 2-step sequence explained in section System on/off procedure. After accessing the software through the direct access icon located at the desktop of the *dedicated computer*, certain warning messages may pop-up on the screen. These are automatic messages related for instance to a disconnected thermocouple, or a sensor recalibration reminder (a procedure recommended by the manufacturer based just on service time). According to MBH, these can just be ignored pressing “OK” to continue. Once into the *testXpert III* software, the user should be facing the main menu, shown here in Table 10. A big portion of the screen is occupied by the four main instances offered by the software: **Set-up testing system** (“configurer système d’essai”), **configure test** (“Configurer essai”), **Run test** (“Réaliser essai”), and **Export test data** (“Visionner résultats”). These are numbered 1,2,3, and 4 in Table 10.

Table 10: Description of the main options appearing on the home menu of the *testXpert III* software.



Software instances (1,2,3 and 4 in the figure above)	
1	“Configurer système d’essai” (Set-up testing system): The configuration of the machine, the communication between <i>testControl II</i> unit and all peripheric components (e.g., load cell, furnace and extensometer) and the sensors is established herein.
2	“Configurer essai” (Configure test): This instance is intended to configure the test itself. Instructions such as type of test, test length, data acquisition and test data management programmed herein.
3	“Réaliser essai” (Run test): This option allows to execute a previously configured test. During the test, it enables in-situ monitoring of all test conditions.
4	“Visionner résultats” (Export test data): This last option offers the user an interactive interface to visualize the results of a test after opening the corresponding *.zs2 file.
Software configuration options (left edge menu in the figure above)	
a	Profile options : This opens a personalization menu for the user interface (language, default options)
b	Open directory : Navigate the PC directory and open a configuration (*.zp2) or series (*.zps) file.
c	Software documentation.
d	Configuration : configuration of miscellaneous basic options entitled to the graphical user interface (GUI) and the software itself. Here, the user can for instance change the language of the software.
e	User guide : an endless off-line user guide with information.
f	System information, related to the identification of peripheric components.

At this point, communication with the *testControl II* unit is in effect. However, no input/output (I/O) signal can yet be processed. To correctly recognize and process all I/O signals, a machine configuration instance must first be loaded into the software. These come in the form of *.zp2 format files containing a set of system and test configuration instructions (1 and 2 in Table 10). To open such a file, the user must first click the folder icon (b Table 10) located at the right edge section of the main menu of *testXpert III* and navigate within the computer directory until the correct file *.zp2 (do not get confused with the *.zs2 series file, where results are stored) file is found. **New tests are often programmed by modifying old *.zp2 files.** This will enable the software to recognize all I/O sensors and machine peripheric components. Once opened, the software will display the in-time information coming from all ports (e.g.: axial load, crosshead position, temperatures, etc.). Any modifications to the current configuration can be saved by either overwriting the current configuration file or by creating a new one based on the previous one. **We highly encourage the user to maintain the organization of the directory and to store the files accordingly.**

To run a test on the machine, the user is presented with two main options:

- (1) Create a new configuration file. In this case, the user does not need to start from scratch, but rather by loading the *.zp2 file that resembles the most to the expected configuration. The user can proceed to modify the file accordingly. The modified file must be stored separately from the original one, taking care not to disturb the file directory organization.
- (2) To initiate a previously existing configuration file. If the user aims to conduct a test in the context of an already existing project and directory, the test can be executed using a previously stored *.zp2 file without the need of creating or storing a new one. Regardless, the user must be aware of checking the correctness of all configuration instances (1 and 2 in Table 10). In particular, the user must modify the initial crosshead position according to the new specimen upon mounting the specimen (see Crosshead ranging). These modifications shall be stored by overwriting the current *.zp2 file, which will be lately used to run the test.

Upon opening the correct *.zp2 file, the user should be facing a main menu screen where information from the main I/O sensors of the machine are displayed alongside the lower edge of the screen as seen in Figure 6.

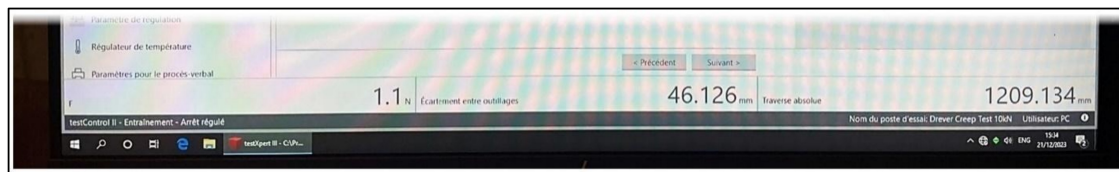


Figure 6: Photograph showing the lower edge of the screen displaying I/O data after recognizing the *testControl II* unit ports. From left to right: force, total axial displacement, and absolute crosshead position.

1.1.2. Configuration of testing system

After opening the correct *.zp2 file, the test programming sequence can finally be started. First, the system (machine, sensors and peripheral components) must be configured through the **Set-up testing system** configuration menu (1 in Table 10). Upon opening this option, the user will be led to a new GUI within *testXpert III*. A dark-gray ribbon with basic actions (Home button, save/save as, and some basic test and data post-treatment faculties) is located in the upper edge of the screen. Below, a short light-gray ribbon allows the user to navigate intuitively among the 4 main software instances (1 to 4 in Table 10) by simply clicking one of the upper screen icons located in the upper edge of the screen. These are highlighted in yellow and green respectively in Figure 7.

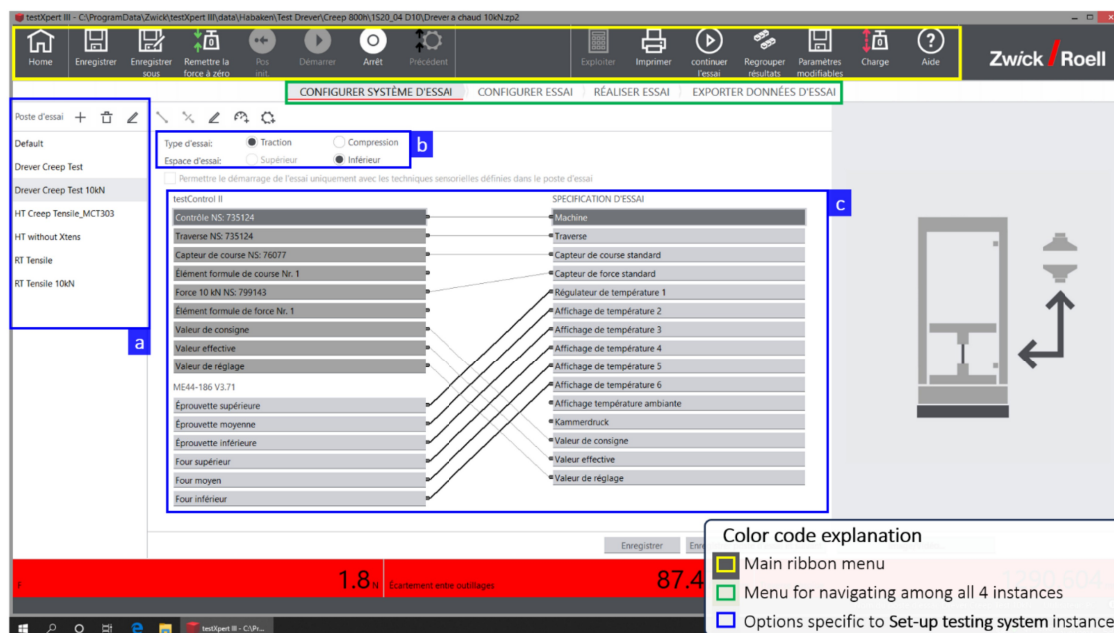


Figure 7: Photograph describing the main options displayed upon accessing **set-up testing system**. The main ribbon menu (yellow) and instances navigation menu (green) are held permanently in place when operating in the software. The options highlighted in blue are exclusive to the **set-up testing system** (“Configurer système d’essai”) configuration menu. In the upper left edge of the screen the, directory containing the currently opened file (*.zps or *.zpz) is displayed.

In Figure 7, the options dedicated to configure the testing system (our current task) are highlighted in blue. To enable user-access to any of these elements (i.e., read, verify, and possibly modify certain parameters), the user must first turn the key of the *testControl II* (the Set-up/test mode selector in Table 7). All testing system configuration options must be thoroughly checked throughout the menus a, b, and c, following that specific order.

- The left edge of the screen (a in Figure 7) is occupied by a list of pre-configured (default and new) combinations of machine + peripheric components. To allow the *testControl II* unit to correctly recognize each of the peripheric components and sensors connected to its I/O ports, the correct combination must be selected. In this case, the configuration selected is named “Drever Creep Test 10kN”, in reference to the 10 kN load cell installed in the machine. It is still unclear how to create a new configuration within this list, as this activity has only been performed by (and might be exclusive to) Z/R certified technicians.
- This brief but important section contains two important options the user must select. In the upper row, the user must select the main type of load the machine will impose during the test: either tensile or compressive. In the lower row, the user must define the position of the specimen according to the crosshead: either in the superior position (between the crosshead and the upper beam) or in the lower position (between the crosshead and the bottom surface, as seen in Figure 2). In this case, a tensile creep test is performed, and all testing devices are positioned within the inferior section of the crosshead. The configuration of Figure 7b is chosen accordingly.

- c. This graphical menu illustrates the relation between the machine and furnace control devices (left column) with the respective digital I/O ports (right column). The modification of these relations (connecting lines in Figure 7c) falls beyond the scope of this instruction manual. However, certain parameters related to the machine and furnace control devices located within the left column of this menu must be verified and modified (if necessary) by the user. These parameters can be accessed by double-clicking the corresponding column element. Upon clicking, a small window showcasing the options or parameters related to that column element will appear in the middle section of the screen. The description of the contents of each of the left column elements and the recommended actions for the user are listed in Table 11.

Table 11: Detailed description of system configuration elements and recommended actions for the user when programming a new test. Elements where actions are required are highlighted in this color (purple of pink, depending on your paper/screen).

	Features configured within the item	Action	Ref.
testControl II (Machine Control unit; MC)			
Control SN: 735124	Load cell regulation options	NO	
Crosshead SN: 735124	Crosshead movement range	YES	MC2
Extensometer SN: 76077	Extensometer gauge length	Only if necessary	MC3
Travel formula element No. 1	—	NO	
Force 10 kN SN: 799143	Load cell force range and limits	NO	
Force formula element No.1	—	NO	
Set value	—	NO	
Actual value	—	NO	
Control point	—	NO	
ME44-186 V3.71 (Furnace Control unit; FC)			
Éprouvette supérieure	Temperature regulation options	Only if necessary	FC1
Éprouvette Moyenne	Temperature regulation options	NO	
Éprouvette inférieur	Temperature regulation options	NO	
Four supérieur	Temperature regulation options	NO	
Four moyen	Temperature regulation options	NO	
Four inférieur	Temperature regulation options	NO	

Detailed explanations on the checking and modification of each of the values are provided hereafter.

MC2

Within this element, the movement range of the crosshead and its initial position (with a mounted specimen) are defined. To this end, the user must mount the specimen into the machine and adjust the crosshead position manually. In the absence of a mounted specimen, the user can skip the configuration of this element for the moment and continue further with the test programming. However, it is imperative to introduce these crosshead parameters after mounting the specimen and before running the test. The full explanation on how to calculate these values according to the mounted specimen is given in section Crosshead ranging.

MC3

This element requires the user to define the default gauge length of the specimen to be tested. The distance must be manually defined within the “Longueur de référence” box highlighted in blue in Figure 8. This length is merely referential and is used only to later calculate the uniaxial strain and strain rate during the test. The modification of any other parameter is strongly discouraged.

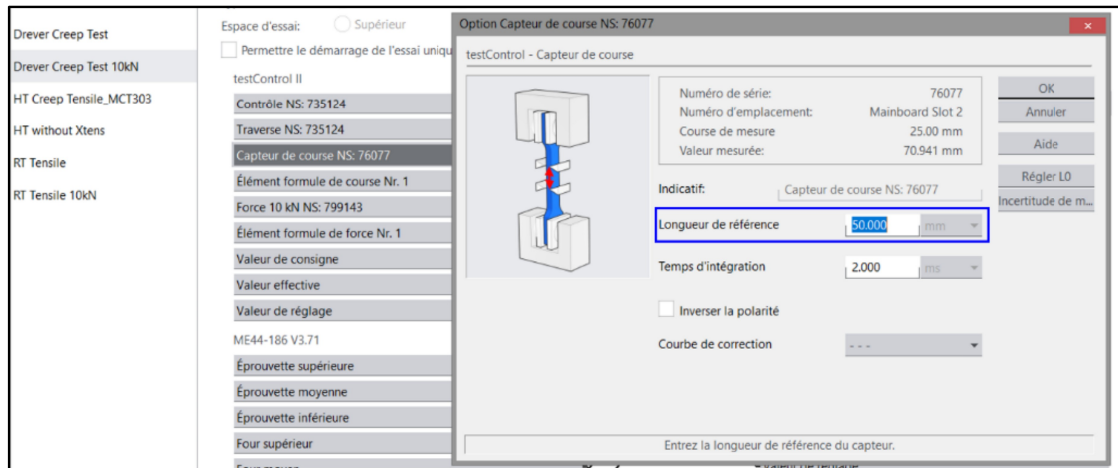


Figure 8: Photograph showing the MC3 menu where the user must define the referential gauge length of the specimen.

FC1

Upon opening this element, the user is presented with a menu that allows to modify key temperature control parameters. This menu can only be accessed on the first element of the furnace column. However, and despite its name (“Éprouvette supérieure” referencing the upper specimen thermocouple), it affects the furnace control unit (**ME44-186 V3.71**). The menu offers the option of modifying two sets of temperature regulation options. The first two options (“consigne de température” and “Rampe de température”, highlighted in red in Figure 9A) fall outside the focus of this document. In contrast, the latter two (“commutation point” and “Minimum temperature ramp”, highlighted in blue in Figure 9A) play an important role in the digital temperature control system during the test.

As explained in the beginning of section 1.1, the thermomechanical loadings of a test are programmed using a block sequence methodology. Let us step into the situation where a block is programmed to induce a temperature change during the test. Upon activation of this block, the initial temperature T_0 will increase gradually until the objective temperature T_1 is reached as seen in Figure 9A. As shown in section CE05, parameters such as objective temperature (T_1), holding time (t_{hold}), temperature ramp ($\dot{T}_B$) are introduced when programming the temperature block itself. This process must be configured seeking to reach the objective temperature in the minimum amount of time (t_1) while avoiding any temperature overshoot (an event likely to occur if we reach T_1 with the temperature ramp ($\dot{T}_1$) introduced during block configuration). The smooth temperature transition observed in the illustration of Figure 9B is the result of the inclusion of a commutation temperature point, from which the control of the temperature increments switches from

the block ($\dot{T}_1$) to the furnace control unit ($\dot{T}_{FC1}$). The commutation point and the minimum temperature ramp are manually defined within the respective boxes highlighted in blue in Figure 9A. This temperature evolution technique is applied ubiquitously during the test.

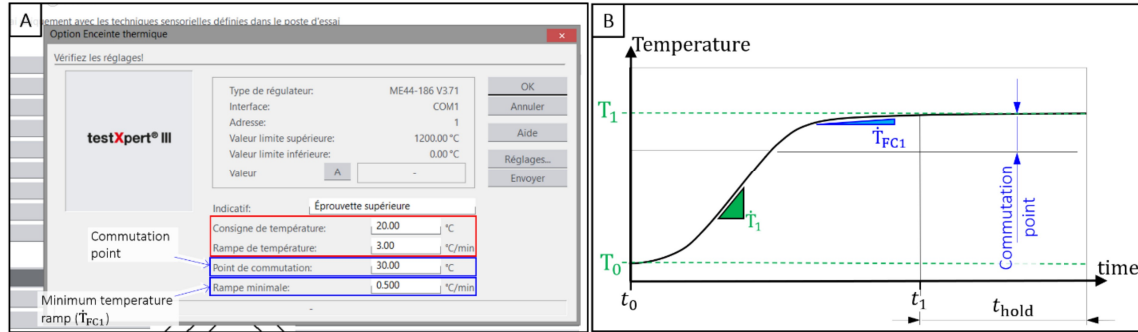


Figure 9: (A) menu of element FC1 for the definition of temperature control parameters used to achieve a smooth temperature transition. (B) Graphical illustration showing the smooth temperature transition achieved as the commutation point and minimum temperature ramp parameters previously defined take over the temperature control of the specimen.

Any modifications performed on the testing system should be saved accordingly (either creating a new file or overwriting the current one). After saving, the user must lock the current system configuration by turning the key of the *testControl II* unit (Set-up/test mode selector in Table 7), selecting **test mode**.

1.1.3. Test configuration

The definition of thermal and mechanical loadings, data acquisition, and pre- and after-test default procedures are defined herein. To access the test configuration menu, click “configuration d’essai” on the navigation ribbon highlighted in green in Figure 7. Upon clicking, the user will be faced with the test configuration menu. All elements needed to configure the test are organized vertically at the left edge of the screen as seen in Figure 10. It is organized so that the user can intuitively navigate through all elements in a descendent order, verifying and modifying parameters accordingly. Upon clicking any element, the configuration menu of the element will be displayed in the middle section of the screen. In Figure 10, the test configuration menu displays the element “définition d’essai”, where type of test and the type of machine are defined.

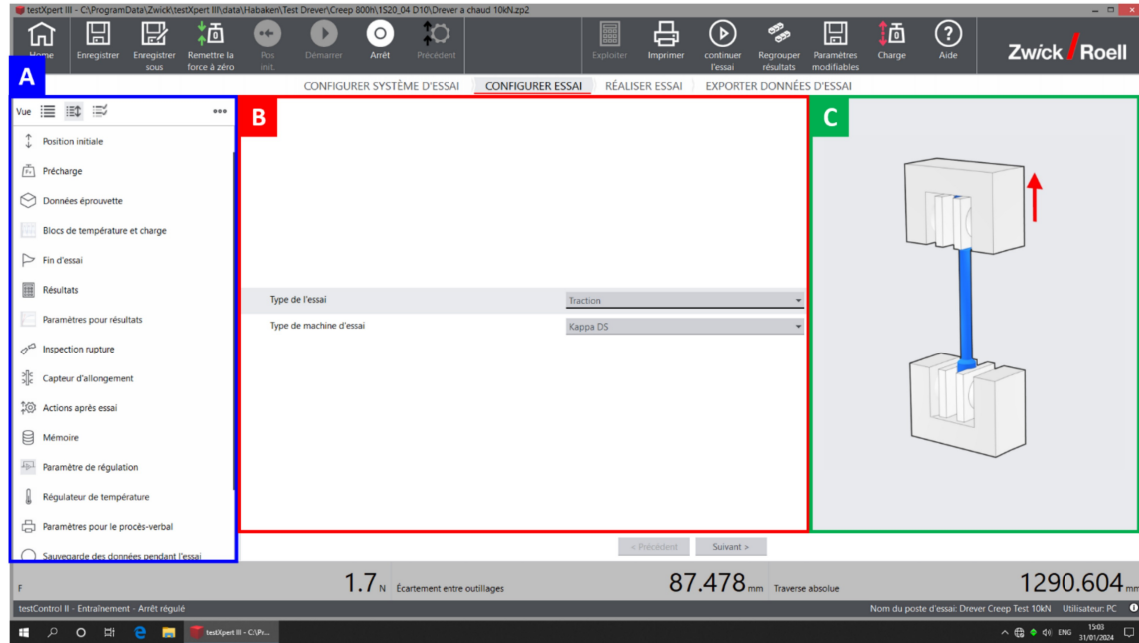


Figure 10: Screenshot of the dedicated computer screen showcasing the test configuration menu. The left edge of the screen (A, in blue) encases the vertical array of test configuration elements (CEs), where the “définition d’essai” (test definition) element is selected. The middle section of the screen (B, in red) is occupied by the set of parameters related to the CE in selection. The right edge of the screen (C, in green) shows an illustration intended to guide the user throughout the element configuration menu.

The user shall navigate through the column of elements (A in Figure 10) and verify (or modify) each test parameter accordingly. During this process, the use of the mouse wheel (scroll) to navigate vertically throughout the menu is completely unadvised due to a detrimental software feature where this movement is not only used for navigation but for selecting elements from a list (e.g., changing an objective load from 10 N to 10 kN in Figure 14). To avoid such events, the user must procure to navigate using exclusively the right and left click mouse buttons. A detailed guide on the contents of each test configuration element along with the recommended actions for the user (i.e., skip, verify, or modify) is given in Table 12.

Table 12: Description and recommended user actions per each of the test configuration elements located within the left column A in Figure 10. The acronyms describing the possible actions are: **S** (skip, test configuration element falling outside the scope of the machine itself), **V** (verify, check if the parameters are correct), and **M** (modify, imperative modification of parameters according to the test). The details on the action (if recommended) are given in subsections CE (“Configuration d’Essai”) after the table.

Title (fr)	Definition of...	Action	Ref.
Définition s’essai	basic test characteristics and conditions	V	CE01
Position initiale	initial grip-to-grip distance (in-situ measurement)	M	CE02
Précharge	an initial axial load	M	CE03
Données éprouvette	specimen geometry	M	CE04

Blocs de Température et charge	the blocks describing the sequence of thermal and mechanical loadings to execute the test	M	CE05
Fin d'essai	condition (mechanical loading or position threshold) to consider end the test	M	CE06
Résultats	results to later print within *.pdf export files	S	—
Paramètres pour résultats	parameters involved in the calculation of results from previous element	S	—
Inspection rupture	loss of load carrying capacity of the specimen	S	—
Capteur d'allongement	maximum range of LVDTs	V	CE10
Actions après essai	instructions to finish the test under ideal conditions	M	CE11
Mémoire	Frequency of data acquisition per block	V	CE12
Paramètre de regulation	PID control parameter	S	3
Régulateur de Temp.	Maximum admissible temperature variation once the objective temperature is reached	M	4
Param. Pour le procès-verbale	standard text information to print within a *.pdf file	S	5
Sauvegarde des données pendant l'essai	period ruling the test data autosaving frequency	V	6
Procès-verbale	filename of *.pdf data export file	S	7
Interfaces export	test data export into text files (*.TRA and *.TR2)	M	8

The recommended actions appearing within the Ref. column in Table 12 are described hereafter.

CE01

The menu displayed here (shown in Figure 10) showcases two basic but important test configuration options related to the system configuration: the type of test ("Type de l'essai"; either *traction* or *compression*) and the type of testing machine ("Type de machine d'essai": in our case, a *Kappa DS*). The user cannot change these options directly, as they are related to previously chosen system configuration options selected in section 1.1.2. The user is given this element as a mere means of verifying these two basic system configuration options. Once the correctness of the data is corroborated, the user can continue towards the next element in the column.

CE02

In this element, the initial grip-to-grip (G2G) distance and the displacement velocity that the crosshead will reach when moving to this initial position are introduced. The G2G distance must correspond to that of the currently mounted specimen, and must be measured manually in the initial position (i.e., low positive non-zero axial load, see Crosshead ranging). **If no specimen is mounted, this element can be safely skipped. However, this distance must be corrected after mounting the specimen and before running the test.** To update this parameter, the user must first mount the specimen into the machine, following the instructions provided in section Crosshead ranging. After updating the G2G distance within the MC2 element (see the configuration of the testing system in section of 1.1.2), the user can just click A (*acquire*, highlighted in blue in Figure 11). Upon clicking, the G2G distance ("Écartement entre outillages pour position initiale") of CE02 will be replaced by that of MC2.

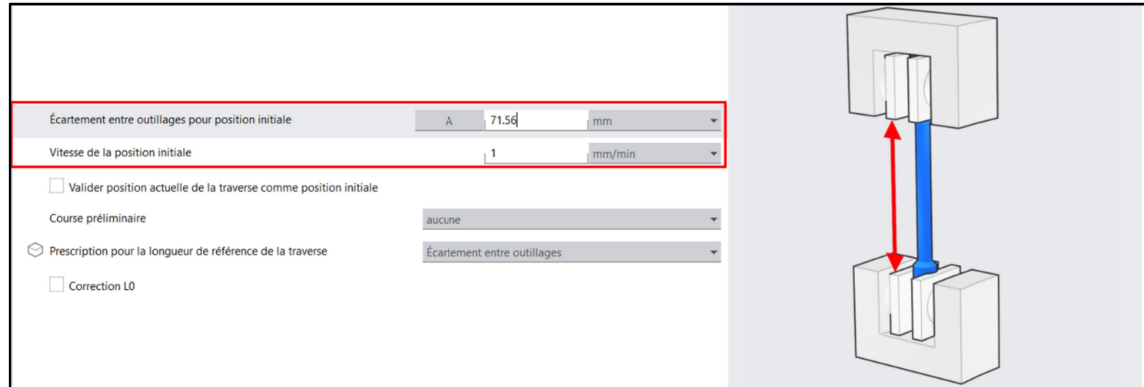


Figure 11: Test configuration menu of configuration element 2 (CE02, "Position initiale"). The red box highlights the parameters modifiable by the user. The figure at right is meant to guide the user through the modification of parameters.

The rest of the options and checkboxes found below the red box in Figure 11 can be safely disregarded.

CE03

A preload is a user-defined axial load applied at the very beginning of the test, so that the actual test (sequential execution of blocks describing all thermomechanical loadings, see CE05) starts with this constant axial load. For instance, a creep test conducted following strict standards such as ASTM E319-11 or ISO-204 indicate that the test must be initiated by the application of a preload roughly equivalent to 10% of the total test load. Overall, initiating a test with a preload ensures safety (by avoiding compressive loads) and standardization of the results by eliminating uncertainties from the experimental methodology. The preload option must first be enabled by ticking the box located in the upper left corner from the configuration panel highlighted in red in Figure 12.

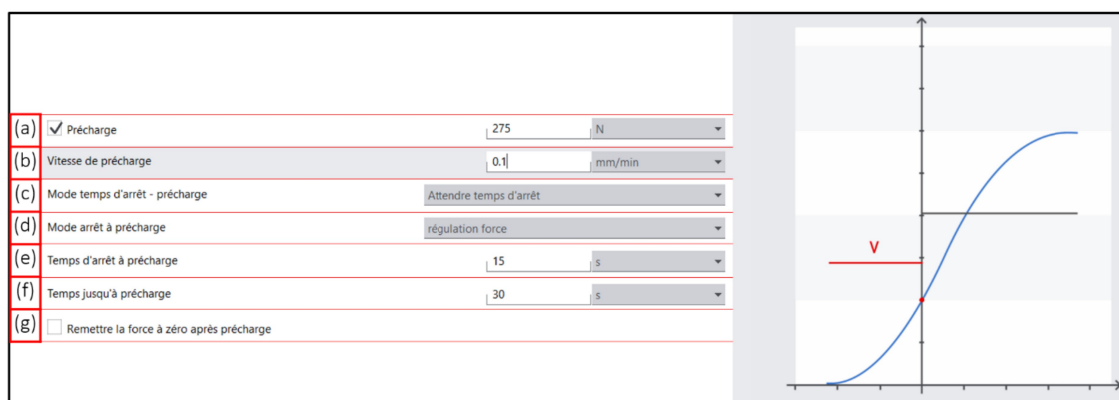


Figure 12: Test configuration menu of configuration element 3 (CE03, "Précharge"). The red box highlights the parameters modifiable by the user.

Upon ticking, the preload parameters located in the same section will activate, enabling user input. These are identified alphabetically from (a) to (f) in Figure 12 and defined here below in Table 13.

Table 13: Definition of preload parameters, in reference to Figure 12.

Axial force during preload Crosshead position during preload	
(a)	<i>Précharge (Preload)</i> : The axial load to be reached during the preload procedure.
(b)	<i>Vitesse de précharge (Standard velocity for preload application)</i> : This is the maximum velocity of the crosshead as it moves from position P_0 to P_1 , where the axial force (a) is reached.
(c)	<i>Mode temps d'arrêt – précharge (Mode for holding time – preload)</i> : Definition of the action upon reaching the total preload. The instruction of “Attendre temps d'arrêt” (waiting until completing the holding time” seen in Figure 12 is selected by default and cannot be changed by the user.
(d)	<i>Mode arrêt à précharge (Mode after finalizing preload)</i> : Definition of control type after reaching the objective preload. The instruction of “regulation force” (regulate the axial load, meaning it will maintain the objective preload during the entire time period) seen in Figure 12, is given by default and cannot be changed by the user.
(e)	<i>Temps d'arrêt de précharge (Time for exiting preload)</i> : Delay to exit the preload stage.
(f)	<i>Temps jusqu'à précharge (Time until preload)</i> : Time during which the preload is held.
(g)	<i>Remetre la force à zero après précharge (return force to zero after preload)</i> . If selected, the specimen will be unloaded until the axial force returns to zero after the preload is applied.

CE04

In this menu, parameters defining the specimen geometry are introduced. These are mostly intended to analyze cross section changes (e.g., during fracture analysis through loss of load carrying capacity). Creep tests (conducted at a constant axial load) do not fall within this category. Regardless, it is recommended to introduce the basic geometry parameters so that the software can correctly display the equivalent axial (engineering) stress. To this end, the user must introduce the geometry type (“Forme éprouvette pour calcul section” in Figure 13) and the geometrical dimensions that enable the software to calculate the cross section of the specimen.

Entrées sur l'éprouvette

☐ Identifiant éprouvette
☐ Type
☐ N° de pièce
☐ Prélèvement
☐ Avis:

Forme éprouvette pour calcul section

Éprouvette cylindrique

Diamètre

10

mm

Facteur de correction de section

1

Valeur négative pour correction de section

0.000

mm²

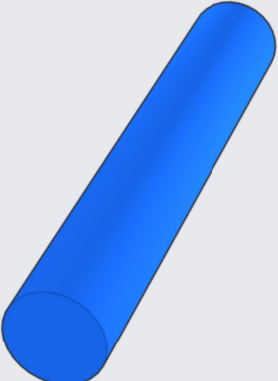


Figure 13: Test configuration menu CE04, “Données éprouvette” (specimen data). The red box highlights the parameters that require user input.

CE05

In this element, the block sequence describing the test is defined. The menu is composed of two main sections. The upper section (highlighted blue in Figure 14) is used to define the total number of blocks forming the sequence. The lower section, highlighted in red, encases the programming of a single block (the first). The thermal and mechanical loadings of each block are programmed following the block execution sequence downwards. In other words, introducing n number of blocks in (c) will create n instances (f) to (l) where the user can access scrolling downwards, block by block. The example of all parameters necessary to define a single block of the sequence is highlighted in red in Figure 14.

(a)

☐ Test selon ASTM F1624

(b)

Nombre de paliers de charge et paliers de température

3

(c)

Nombre de cycles de bloc

10

(d)

☐ Répéter déroulement jusqu'à la rupture

(e)

☐ Activer la régulation en 2 points

(f)

Température de consigne

1000.0

°C

(g)

☒ Rampe de température

25

°C/min

(h)

Point de charge

Force standard

275.00

N

(i)

Vitesse Point de charge

contrôle position

0.1

mm/min

(j)

☒ Contrôle position Point de charge

(k)

Action après point de charge

Régulation force, maintenir

(l)

Temps d'arrêt

15

min

Température de consigne 2

1000

°C

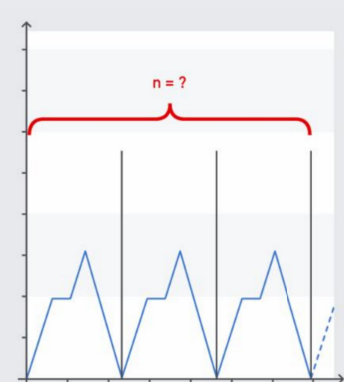


Figure 14: Test configuration menu of CE05, “Blocs de température et charge” (temperature and stress force loading blocks). The blue box highlights the configuration of the sequence itself, whereas the red box encases the configuration of a single block from the sequence.

A detailed explanation of the effect of each of the configuration parameters highlighted in blue in Figure 14 is given in Table 14. Those highlighted in red are described in Table 15.

Table 14: Definition of parameters related to the block sequence configuration according to the letter-tags assigned previously in blue in Figure 14.

Sequence configuration	
(a)	Check box to enable a loading methodology following the ASTM F1624 standard. It is intended to consider possible hydrogen embrittlement observed in some alloys. This is addressed by applying an incremental step loading procedure. When conducting creep tests, this checkbox must remain unchecked.
(b)	Box where the user must introduce an integer number defining the total number of blocks conforming to the test. The test loadings specific to each block are configured below within the parameters (f) to (l), highlighted in red in Figure 14. After introducing the number, a single set of block parameters will be displayed per block. They are organized vertically from the first (top) to the last (bottom) block of the sequence.
(c)	If the block sequence (for instance, to generate cyclic thermomechanical loadings) is required to be repeated, the user must tick the left-box and introduce the number of repetitions (cycles) of the block sequence on the right elongated box. If the block sequence does not need to be repeated, the left box must remain unchecked.
(d)	This checkbox must be ticked in case the user wishes to repeat the block sequence indefinitely until the test is stopped either manually or after the rupture of the specimen is detected.
(e)	UNKNOWN. This box remains unchecked by default.

Table 15: Definition of parameters related to block test configuration according to the letter-tags assigned in red in Figure 14.

Axial force variation imposed in block		Temperature variation imposed in block	
Block configuration			
(f)	The objective temperature of the block (T_1 in Figure 9). Upon starting this block, the initial temperature of the specimen (T_0) will change until T_1 is reached. The maximum heating or cooling rate ruling this process is introduced later in (g). In case that $T_0 = T_1$, the temperature is just held constant across the entire length of the block.		
(g)	The maximum heating/cooling rate ruling the temperature evolution of the block. This parameter appears to be optional, depending on the ticking of the checkbox located on the left side of (g). Nevertheless, it is recommended that the user introduces the maximum temperature rate in relation to the maximum furnace capabilities (this information is provided in Table 3).		
(h)	The objective mechanical load of the block. First, the loading method (i.e., force or displacement) must be selected from the list located in the left-side light gray bar. The magnitude of the load is then written in the white box space, and the unit of the respective load is selected from the right-side light gray bar. In the example provided in Figure 14, an axial force ("Force standard") of 100 N is introduced. Be careful to always check the content of the light gray bar lists as they can be accidentally modified when navigating using the mouse wheel (scroll). To avoid such events, procure navigating using exclusively the right and left click mouse buttons. This advice must be complied with during this entire operation.		
(i)	The maximum displacement rate (velocity) of the crosshead during axial load variations. In other words, this will be the maximum crosshead velocity until the objective mechanical load introduced in (h) is reached.		
(j)	Throughout this checkbox, the user indicates that all automatic crosshead movements performed with the objective of holding the objective mechanical load after it has been reached will be ruled by the maximum crosshead velocity introduced in (i).		
(k)	Control type imposed after reaching the objective mechanical load. In this case, the option "regulation force, maintenir" (Force regulation, hold) is indicated (i.e., reach and hold objective axial force for the duration of the block).		
(l)	Definition of the holding time from the moment when the objective thermal or mechanical load is reached.		

CE06

The "Fin d'essai" element from the column is intended to introduce user-defined limits amongst the test variables upon which the test will be automatically stopped. The test configuration menu of element CE06 shown in Figure 15 allows the user to introduce limits for stopping the test under three non-exclusive

conditions: (a-d) stopping upon reaching an axial force limit, (e-g) stopping upon reaching a displacement limit, and (h) stopping upon reaching a thermal limit.

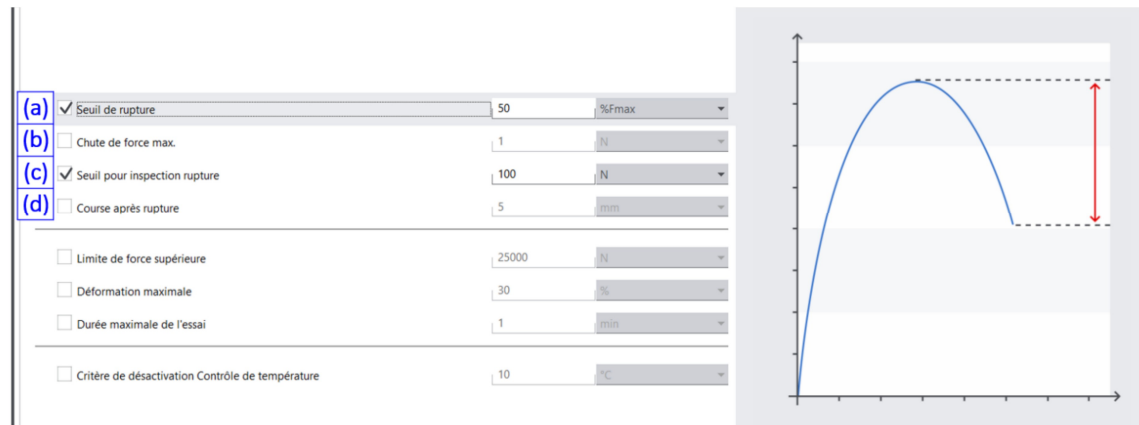


Figure 15: Test configuration menu of element CE06 (“Fin d’essai”), where the test finalization based on the loss of load carrying capacity of the specimen under displacement-driven tests is defined.

The parameters shown in Figure 15 have been introduced by Z/R technicians and were recommended as default settings upon request. Nevertheless, they can greatly influence the outcome of non-destructive tests of any kind. A detailed explanation of the meaning and influence of each of the parameters is provided in Table 16.

Table 16: Description of the user-defined options defining the test finalization under the criteria of loss of load-carrying capacity.

Force-controlled rupture criteria: these are intended for the detection of the loss of the load carrying capacity of the specimen (softening). Such event is set to occur when the total axial load falls below a user-defined minimum	
(a)	“Seuil de rupture” (Rupture threshold): this criterion is intended for the detection of the loss of the load carrying capacity of the specimen (softening). Once a certain force decrement threshold has been reached (e.g., 50% of maximum force in Figure 15), the test is stopped.
(b)	“chute de force max.” (Maximum force overshoot): a force overshoot prevention can be useful to avoid overloading of machine components and ensure test reliability. Such an event is detected by defining a superior limit in either force units (N) or percentage of maximum force (% , like in (a) in Figure 15).
(c)	“Seuil pour inspection rupture” (Rupture inspection threshold): Force-controlled rupture criterion will be activated after this axial force is reached. This value is often equal to the preload.
(d)	“Course après rupture” (Distance after rupture): It is the additional distance to be held upon fracture detection. In such a case, the option “Vitesse pour course après rupture” (Velocity for distance after rupture; the maximum velocity upon which the above distance will be reached after rupture) pops up for the user to define.

(e)	“Limite de force supérieure” (Superior force limit): It is the maximum admissible force allowed to be recorded during the experiment. It is useful when conducting displacement-driven tests
(f)	“Déformation maximale” (Maximum deformation): The user can herein introduce a maximum deformation upon which the test will be stopped.
(g)	“Durée maximale d’essai” (Maximum test duration).
(h)	“Critère de désactivation Contrôle de température” (Criterion for deactivation of temperature control): UNKNOWN.

CE10

Definition of the maximum detection range of the LVDTs used to measure the axial deformation of the specimen. This machine in particular uses two LVDTs operating independently. They connect to the base of the linear extensometer as seen in Figure 1. The work principle is similar to that of a piston, where the movement of the inner rod is interpreted as the axial deformation of the specimen. The maximum range of the transducers is 50 mm. This value is therefore introduced in the corresponding test configuration menu of the element as seen in Figure 16.

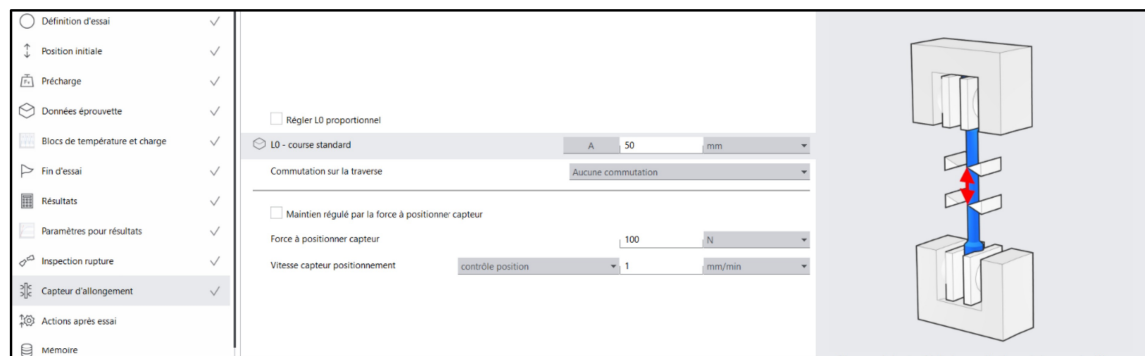


Figure 16: Test configuration menu belonging to the element CE10 (“Capteur d’allongement”).

CE11

This element contains the instructions to follow after a non-destructive test is completed. Upon reaching the end of the test (e.g., after reaching a maximum admissible test time or deformation), the machine will execute these instructions automatically. Here, the user must configure the process throughout which the machine components (crosshead and furnace) are driven to a state that allows the specimen to be safely dismantled. It consists of two main activities: controlled unloading (force decrement) and cooling down (room-temperature). The configuration menu is shown in Figure 17.

○ Définition d'essai	✓		
↕ Position initiale	✓		
⏮ Précharge	✓		
📁 Données éprouvette	✓		
🔧 Blocs de température et charge	✓		
🚩 Fin d'essai	✓		
📊 Résultats	✓		
⚙️ Paramètres pour résultats	✓		
🔍 Inspection rupture	✓		
📏 Capteur d'allongement	✓		
⚙️ Actions après essai	✓		
📁 Mémoire			
⚙️ Paramètre de régulation			
🔧 Régulateur de température			

Entrées après essai		☐ Évaluation optique ☐ Entrées pour rupture ☐ Concerne ☐ Commentaire
(a)	☐ Régler la position initiale après l'essai	
(b)	☒ Décharger éprouvette	
(c)	Force maxi admise en fin d'essai	200 N
(d)	Vitesse de décharge	0.2 mm/min
(e)	☒ Température de consigne après fin essai	25.0 °C
(f)	Ecart de température admissible Refroidissement	15.00 °C
(g)	☒ Refroidir rampe de température	20.00 °C/min
(h)	Force avant le refroidissement	200.00 N
(i)	Vitesse force avant refroidissement	0.10 mm/min

Figure 17: Configuration menu of element CE11 (“actions après essai”), where the actions to be carried out upon test finalization are configured. Here, the user defines the process throughout which the specimen is unloaded (reaching a minimal axial load or position) and cooled down to room-temperature.

The different configuration options are explained in Table 17.

Table 17: Detailed description of the different options of CE11 describing the automatic set of actions to be performed upon test finalization.

Actions après essai: Process throughout which the specimen is unloaded (reaching a minimal axial load or position) and cooled down to room-temperature	
(a)	“Régler la position initiale après l’essai” (Return to initial position after test). This box must be checked if the crosshead is required to return to its original position after the test is performed. It is not advisable, as returning to the initial position (i.e., initial crosshead position) after permanent deformations took place in the specimen could lead to the generation of compressive loads that could prove detrimental to the integrity of the machine and its components.
(b)	“Décharger éprouvette” (Unload specimen): Checkbox to enable the unloading process of the specimen. It is recommended to check this box.
(c)	“Force maximale admise en fin d’essai” (Maximum admissible force after test end): It is the force that will be imposed after the test is finalized. Impose a positive force equal in magnitude to the preload.
(d)	“Vitesse de décharge” (Unloading rate): it is the maximum crosshead displacement rate (velocity) during the unloading procedure.
(e)	“Température de consigne après essai”(Objective temperature after test): Upon finalizing the test, the machine will cool down the specimen until this temperature is reached.
(f)	“Ecart de température admissible Refroidissement” (Admissible range cooling-down temperature): It is the maximum admissible range that defines the fully cooled down state.

(g)	“Refroidir rampe de température” (Temperature rate when cooling): It is the maximum cooling rate achieved during the cooling process.
(h)	“Force avant le refroidissement_” (Force before cooling down): It is the standard axial force that will be held constant during the cooling down process.
(i)	“Vitesse force avant refroidissement_” (Force velocity during cooling down): The maximum velocity that the crosshead will achieve when attempting to hold the cooling down force (h) during the cooling process.

CE12

The element “mémoire” is used to define the parameters ruling the data acquisition frequency during the test. The frequency is defined per each block (including the preload as “block 1” in Figure 18). The blocks are organized in order from top (preload) to bottom (last block) as seen in Figure 18.



Figure 18: Screenshot of “Memoire” configuration menu.

Following user configuration, the raw data acquired during the test will be averaged and recorded at discrete intervals of axial displacement, time, and force. These are not exclusive, meaning that data can be recorded every time any of the previous three criteria (i.e., displacement, time or force) is reached. A detailed description of each of the three interval criteria is provided in Table 18.

Important: According to Z/R technicians, one must be aware not to underestimate the data acquisition frequency in order to avoid the generation of a file too big to be handled by testXpert III software. Following their advice, the optimal frequency is indicated within Table 18.

Table 18: Detailed description of the displacement, time, and force interval for data acquisition frequency.

Actions après essai: Process throughout which the specimen is unloaded (reaching a minimal axial load or position) and cooled down to room-temperature	
course	“intervalle... - course” (Displacement-driven interval). Definition of data acquisition intervals defined based on the axial displacement. The user can select the displacement transducer (i.e., crosshead or LVDTs) interval unit, and the unit.
temps	“intervalle... - temps” (Time-driven interval). Definition of data acquisition intervals defined based on the time. The standard time interval advised by Z/R is of 2 min.
force	“intervalle... - force” (Force-driven interval). Definition of data acquisition intervals defined based on the axial force.

1.2. Specimen mounting

To mount the specimen into the machine, the user should prepare two working zones:

- Working zone 1 (**WZ1**): The creep machine, including all peripheric components and sensors involved in the experimental procedure.
- Working zone 2 (**WZ2**): A solid horizontal surface located in proximity to the machine (e.g., a table), where the components and tools needed to mount the specimen train must be placed in an organized manner. The “specimen train” is composed by the upper and lower rod, extension rod (if needed), high temperature adapters and the specimen itself; see Figure 19(a).

Photographs of working zones 1 and 2 for M&S laboratory are presented in Figure 19(a) and (b) respectively. On WZ1, the machine and the *testControl II* unit must be both turned on (see System on/off procedure). All components and tools involved in the assembling of the specimen train into the machine must be placed on the WZ2 and must remain upon reach during the process. A summary of all components and tools needed in each of the working zones is given in Table 19.

Table 19: Brief description of all components and tools necessary to perform a correct specimen mounting process into our Z/R Kappa 100 DS creep machine.

Working zone 1 (machine, Figure 19(a))		Working zone 2 (wooden table, Figure 19(b))	
Machine and components	Tools	Specimen assembly	Tools
☐ Machine (open) ☐ Thermocouples ☐ Extensometer	☐ Caliper ☐ Metallic ruler ☐ Tweezers ☐ NiCroSil cable ☐ Allen key ☐ Flashlight	☐ Specimen (clean) ☐ Puling rods ☐ Extension rod* ☐ High temperature adapters	☐ Thermal paste ☐ Gloves ☐ Paper towels

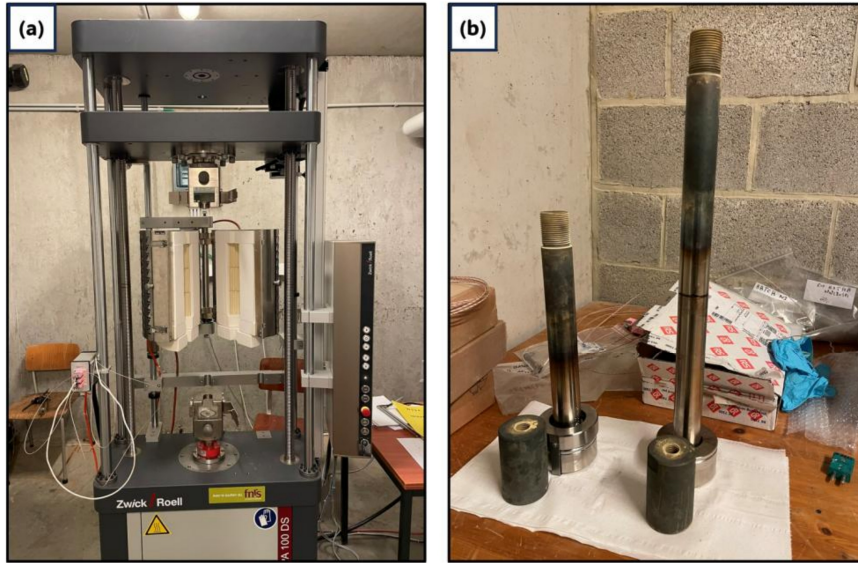


Figure 19: (a) working zone 1: The Z/R Kappa 100DS creep machine is located. (b) Working zone 2: a wooden table located at the opposite side of the room, where the system is composed of the specimen, the high-temperature adapters and pulling rods are mounted.

At this point, the machine and all components must be at room temperature. The furnace and both upper and lower pulling rod mounting boxes must remain fully open (as seen in Figure 19(a)). The mounting process starts in WZ2. Here, the user must put together the specimen train system following the step-by-step guide provided in Table 20.

Table 20: Step-by-step guide for mounting the specimen train system, composed of the specimen, the high temperature adapters and the pulling rods.

1	Preparation: Verify that all tools and specimen train assembly components (WZ2 components) are found on or within reach of the table. Wearing gloves is highly recommended as it avoids direct contact with the specimen and thermal paste.
2	Mounting of specimen to the high temperature adapters
a	Start by adding a small amount of thermal paste on the male thread of the specimen. Screw the high temperature adapters onto the specimen. Take special care of:
b	- Screw the specimen firmly enough to withstand the test, but not too deep as to make sure that the removal is easier. - Use a disposable paper towel to remove any excess of thermal paste.
3	Mounting of pulling rods
a	If needed (for D06 specimens only), screw up the pulling rod extension piece between the main circular mount and the pulling rod intended to go into the furnace.
b	Apply a small amount of thermal paste on the male thread section of the pulling rods.

-
- c Screw the specimen system previously mounted in step 2 of this table onto the lower pulling rod. In case of using an extension, the lower pulling rod is that with the extension rod (see the extension pulling rod at right-side in Figure 19(b)).
 - d Pick up the upper pulling rod with both hands and carefully screw it down into the upper high temperature adapter until all threads are screwed. Make sure of cleaning any thermal paste excess with a disposable paper towel.
-

Once finished the mounting of the specimen train, following the instructions provided in Table 20, it is steady enough to stand vertically on the wooden table. **Beware the entire system weighs around 20 kg. Be extremely careful during manipulation.** With the machine turned on, use the up/down crosshead pushbuttons located in the *testControl II* peripheric (see Table 7) to move the crosshead. To mount the specimen train into the machine, follow the instructions provided in Table 21.

Table 21: Detailed instructions to manipulate and mount the specimen train into the creep machine.

1	Preparation: Make sure that the machine is turned on and the communication between machine and peripheric components is established (see Table 7). Use the up/down crosshead pushbuttons located in the <i>testControl II</i> to manually displace the upper crosshead.
2	Mounting of the specimen train
a	Take the specimen train firmly (with both hands) and carry it to the machine. Place it into the machine by clinging it from the upper pulling rod mounting box, as seen in Figure 20 (a1). The bottom part should be outside the lower box (see Figure 20 (a2)).
b	Use the down push button to slowly decrease the crosshead distance until the bottom part of the specimen train fits loosely* inside the lower mounting box. *: The specimen train should be clinging from the upper box, so the force transducer should be recording 0 (N).
c	Verify that the specimen train is completely vertical. Push it inwards and close the upper box (as seen in Figure 20 (b)). Make sure that there is still no tension in the specimen train (i.e., lose contact, no force recorded on the load cell). Do not close the lower box until the crosshead maximum and minimum positions are recorded (see Crosshead ranging).

Once the specimen is clinging from the upper box as seen in Figure 20 (b), the user must finish the specimen train mounting by indicating the initial crosshead position of the specimen.

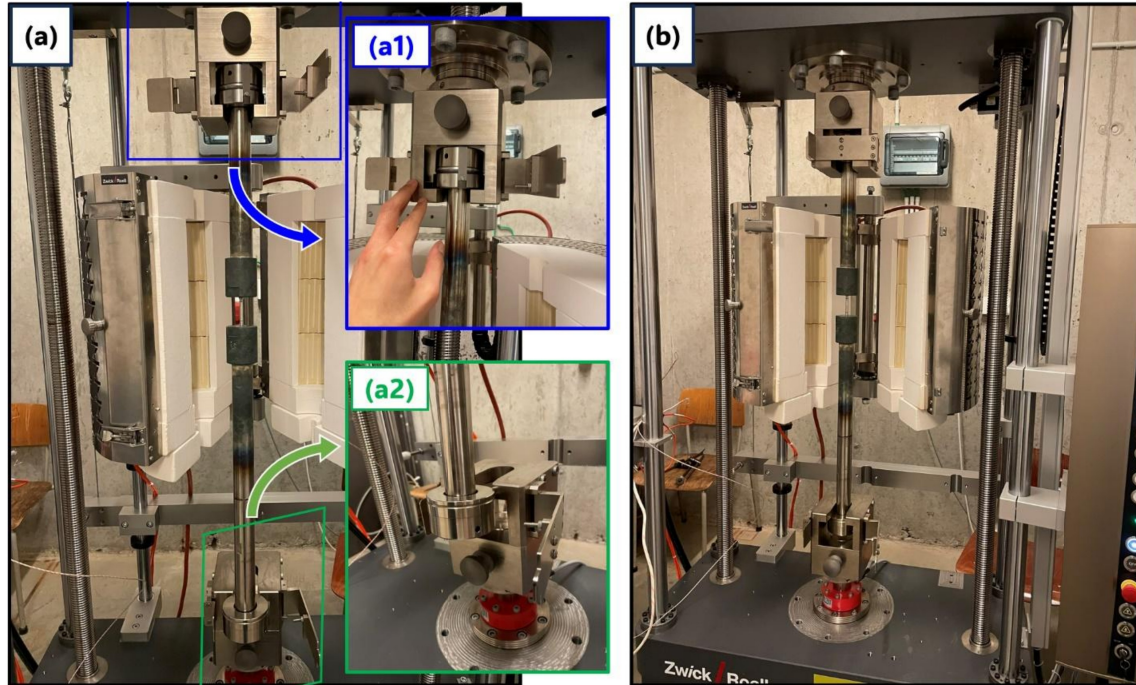


Figure 20: Photographs describing the process of mounting the specimen train into the creep machine.

1.2.1. Crosshead ranging

The crosshead position (displayed as “absolut traverse” at the bottom part of the screen) indicates the distance between the lower crosshead and a reference found within height of the load cell. In the current crosshead configuration (i.e., with the specimen train found below the moving crosshead, see Figure 20), it should indicate a value of around 1200 mm. The range of movement of the crosshead is limited to a maximum and minimum position, which the user must introduce manually upon mounting a new specimen train. To do this, one must follow the sequence of steps provided hereafter:

1. Initiate the crosshead recording manually from the element menu MC2. To edit this menu, the *testControl II* mode selector must be set in “Setup” mode (see Table 7 for more details). This will enable the editing of the options within the crosshead element menu MC2. A screen capture of the menu is showcased in Figure 21.
2. Move the crosshead upwards by pushing the corresponding push button until the force recorded by the load cell (displayed at the bottom left part of the screen, see Figure 6) reaches small positive value (e.g., in the order of $10\text{ N} < F < 20\text{ N}$). Beware that keeping the push button pressed for long time results in faster crosshead movement. To avoid losing control over the crosshead position, it is recommended to push briefly when approaching the contact point.
3. Secure the position by closing the lower box.

Upon succeeding in following all these steps, the crosshead position displayed as “absolut traverse” at the bottom part of the screen is deemed to be the initial crosshead position. However, in MC2 element menu, the minimum crosshead position that the user must introduce must be introduced as $\sim 1\text{ mm}$ below

the initial crosshead position. For instance, the crosshead position displayed in Figure 6 is of 1209.134 mm; therefore, the minimum crosshead position introduced by the user should be 1208 mm. This little distance gap is intended to account for possible uncertainties or miscellaneous measurement errors occurring during the subsequent adjustments. The upper limit is intentionally left as the maximum (default). In case of a specimen fracture during testing, the upwards movement of the crosshead is automatically stopped by redundant electrical and mechanical stopping systems (see Figure 21).

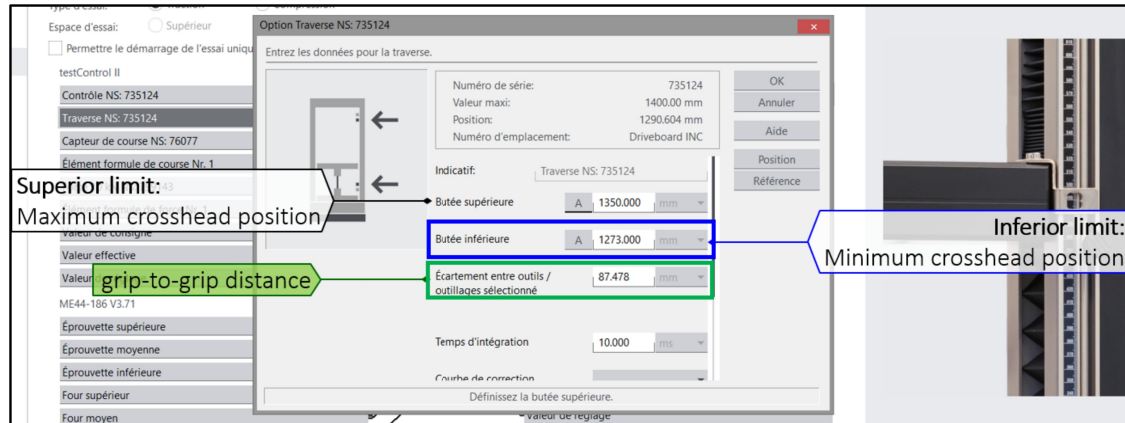


Figure 21: Photograph of the parameters menu for element “Crosshead SN:735124” (MC2).

1.2.2. Thermocouple attachment

The next step consists in attaching the thermocouples onto the specimen. The current system configuration allows for the use of 2 K-type thermocouples. These correspond to the specimen’s upper and lower temperature recording. To do this, one must follow a simple 4-step procedure explained graphically in Figure 22 A, B, C and D. The attached thermocouples are shown in Figure 22E.

When performing this task, the user must procure to keep the following safety recommendations in mind:

- The thermocouples are intended to record the upper-and lower-specimen temperature, and must be attached accordingly onto their corresponding upper and lower sections of the specimen.
- As seen in Figure 22E, a space of approximately 5 mm between the thermocouples and their corresponding collars is observed. This is done purposely to later allow the mounting of the extensometer.
- For the sake of comfortability, it is recommended to install the lower thermocouple first.

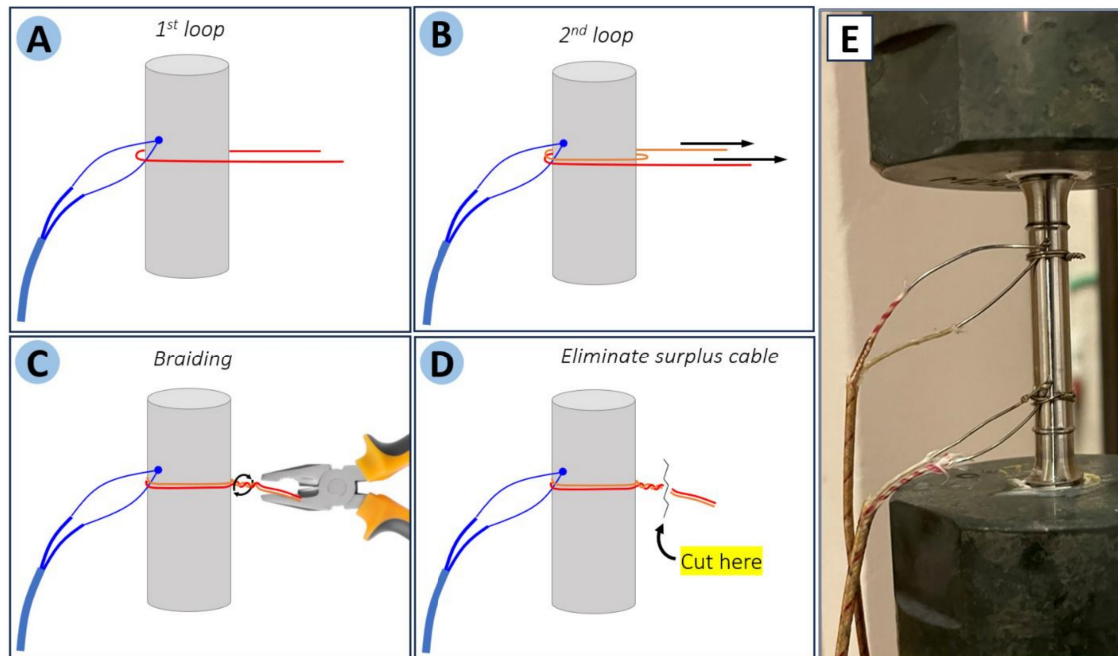


Figure 22: (A to D) correct attachment procedure of thermocouples onto a creep specimen. (E) Result after following the correct thermocouple attachment procedure onto a D06 specimen.

1.2.3. Grip-to-Grip distance

The user must now measure and introduce the grip-to-grip (G2G) distance into the software. This distance corresponds to that between the upper and lower grips (i.e., High-temperature specimen adapters). It must be measured accurately with a caliper as seen in Figure 23. Once ascertained, the measured magnitude must be introduced by keyboard into the “position initiale” box of menu CE02 (see Figure 11).

The measurement of the G2G distance can be performed with or without the thermocouples attached. For instance, Figure 23 shows the measurement procedure being performed before the attachment of the thermocouples.

1.1.1. Extensometer mounting

To perform this task safely, MBH recommends the presence of two people.

To mount the extensometer, one must first have knowledge of all ceramic components that will be used in the experiment. These (all ceramic inserts), along with the thermal paste and an Allen key, must be positioned in an organized manner within reach of the mounted specimen train as seen in Figure 23. Given the extensive use of the extensometer, some small dents on the threads of bolts and hex nuts may appear, which lead to compatibility problems among them. Make sure that the 4 bolt-nuts pairs are compatible with each other. To do this, test the compatibility screwing by hand.

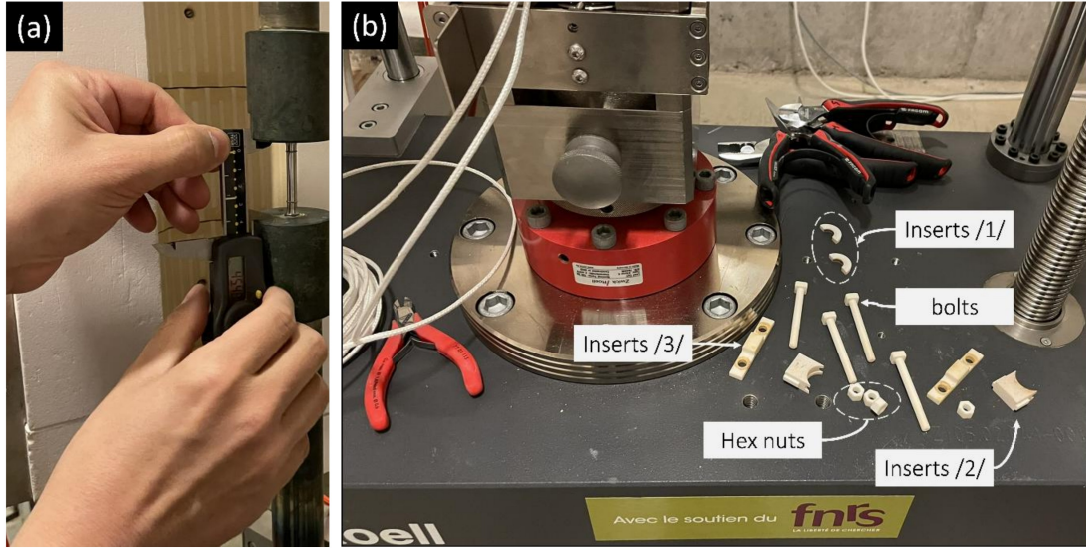


Figure 23: (a) Measurement of grip-to-grip distance on a D06 specimen using a caliper. (b) Tools in reach of the technician and required for the extensometer mounting process.

As seen in Figure 23(b), all components needed for mounting the extensometer are generally placed on the flat gray surface of the machine, near the load cell. Once the layout is ready, the extensometer mounting procedure can be safely performed. A graphical explanation of the procedure is provided in Figure 24. A brief explanation of each of the steps is provided hereafter.

1. Take the extensometer from the box and place it gently in Zone 2 (wooden table, see Figure 19(b).
2. Mount 2 of the 4 the ceramic inserts type /1/ (see Figure 23(b)) on the corresponding grooves located in both upper and lower plates of the extensometer. The completion of this step is showcased in Figure 24(a).
3. Grab and lift the extensometer gently **with both hands**. Carry it in vertical position to mount it on the specimen train in the creep machine. Beware to tilt the extensometer when performing this task (carrying it in a fully vertical position may allow the ceramic inserts to fall to the ground). Once in the machine, attach the extensometer to the specimen, taking care of matching the ceramic inserts groove with the specimen collars. Here, the user must push the extensometer plates inwards to keep it in place (see Figure 24(b)). **Take care not to push too hard, but rather gently enough to keep it from moving or falling.**
4. **This task can be performed by the second person in the room; however an experienced technicians (MBH) can perform this with one hand.** Starting from the upper extensometer plate:
 - i. Pick the rest of the ceramic components (/1/ and /2/) and mount them on the upper plate. The result of this step should be that shown in Figure 24(c).
 - ii. Attach the two upper bolts from behind and mount the upper ceramic insert /3/. Keep one hand always on the extensometer. Following these steps correctly leads to Figure 24(d).
 - iii. Add a small amount of thermal paste at the bolt thread section in contact with insert /3/.

- iv. Screw up the two upper hex bolts by hand. Be careful and gentle when doing so, remember these are ceramic components. The completion of (iv) should lead to the upper mounting section to be complete.
 - v. Perform (i), (ii), (iii) and (iv) for the lower plate.
- 5. Let go of the extensometer. By this point, if all steps have been followed correctly, it should be able to hold onto the specimen by itself. The completion of this step is shown in Figure 24(e).
- 6. Attach the extensometer LVDTs with the aid of an Allen key. Take care not to put too much pressure on the ceramic components in the process.

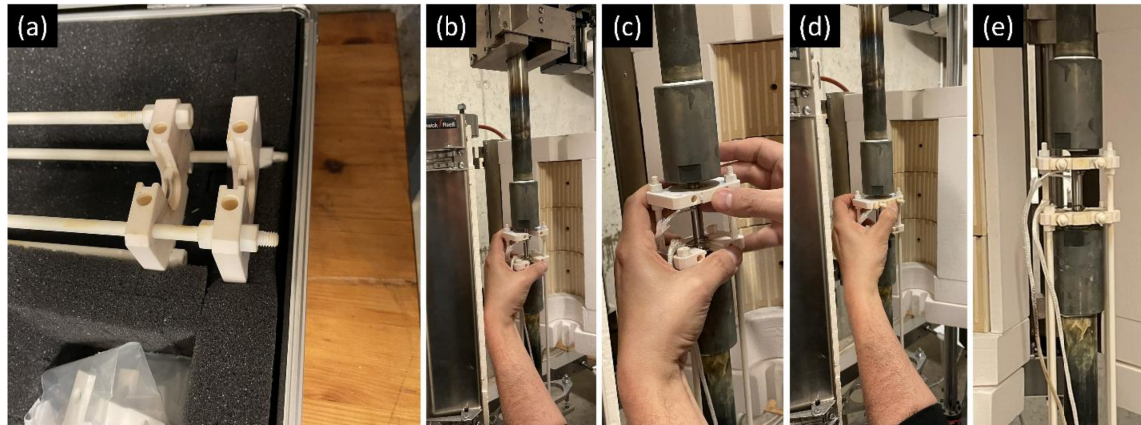


Figure 24: Sequence of photographs (a) to (e) showcasing the process to safely mount the extensometer onto a cylindrical specimen.

Short report: Numerical predictions of axial forces in creep machine after cooling

Student: Carlos Rojas Ulloa
Supervisor: Anne Marie Habraken
Co-Supervisor: Laurent Duchêne

Summary

This document contains a numerical study seeking to ascertain the magnitude of tensile axial loadings generated in the creep machine after a high temperature test is interrupted. A worst-case scenario where the machine crosshead is locked after an electric outage is considered. Upon crossheads locking, the tensile axial load may increase drastically as the specimen is cooled down. Such an event could potentially endanger the integrity of some machine components.

The study allowed to ascertain that the maximum axial force reached after a worst-case scenario is largely determined by the test temperature and the accumulated viscoplastic strain. The effect of the initial mechanical load associated with the creep test is negligible in comparison.

In general, axial forces surpassing the 10 kN nominal force of our load cell are observed for all specimen geometries under such circumstances. The load cell is however designed to withstand up to 300% of its nominal force without mechanical damage (i.e., 30 kN). Calculations presented herein show that specimens of geometry D06 (6 mm cylindrical specimens) do not surpass the 20 kN; they are therefore deemed safe for use in combination with a 10 kN load cell under any circumstance. In contrast, specimens of geometry D10 are prone to exhibit forces beyond 30 kN and up to 50 kN; they are therefore deemed as unsafe under a worst-case scenario. The decision of changing the load cell for a 100 kN one load cell should be made with consideration of the load level, as the lower definition of the 100 kN load cell may affect the reliability of the test results.

List of contents

1. Analytical description of the problem	1
2. Application on Incoloy 800H	4
3. Concluding remarks.....	5

1. Analytical description of the problem

Let us stand in a worst case scenario where a creep test conducted at a temperature T_a at constant stress σ_a with a correspondent axial force F_a is suddenly interrupted due to an electric outage. In this situation, the crosshead of the machine will instantaneously lock in its current position, the furnace and all peripheric components will stop working, and the specimen will progressively cool down naturally. With time, the thermal contraction of the specimen halted by the locked crosshead will derive in the generation of an incremental axial load that could surpass the maximum admissible load of some of the machine components.

To better understand this problem from an analytical perspective, the situation described hereabove is subdivided into two stages: Stage 1, where the test is being conducted with normality, and stage 2, where the test is interrupted, the machine and peripheric components stopped, and the specimen is found at a temperature $T_b < T_a$. The situation is described graphically in Figure 1.

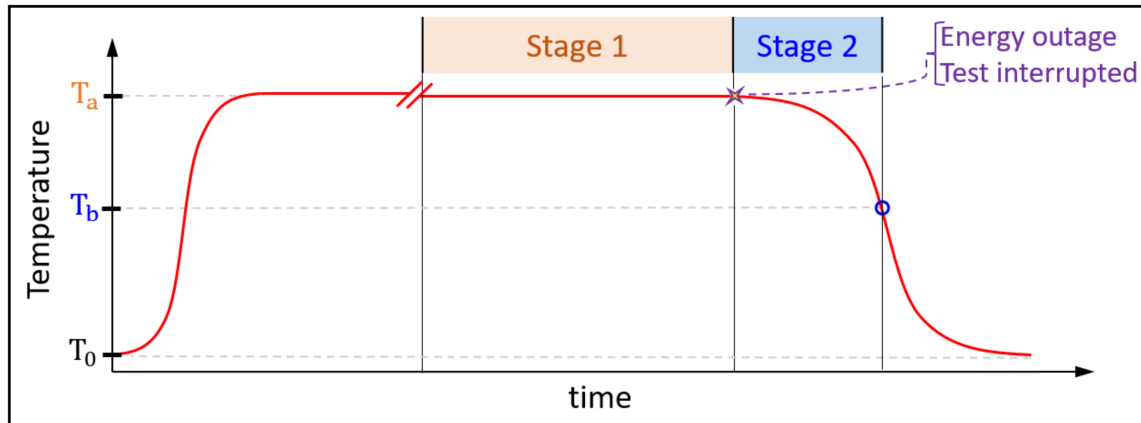


Figure 1: Graphical description of the temperature history of a specimen after a test is interrupted.

In **Stage 1**, the total strain in the specimen (ϵ_1^{tot}) is the result of the contribution of three strain components: the elastic strain (ϵ_1^e), the thermal strain ($\epsilon_{T_0 \rightarrow T_a}^{th}$, consequence of the temperature increment from room temperature (T_0) to the testing temperature (T_a)) and the creep viscoplastic component (ϵ^{vp}). The summation of strains is shown in Eq.(1).

$$\epsilon_1^{tot} = \epsilon_{T_a}^e + \epsilon_{T_0 \rightarrow T_a}^{th} + \epsilon^{vp} \quad (1)$$

From Eq.(1), the first two (elastic and thermal) are considered as recoverable strains, whereas viscoplastic deformations are deemed permanent. The stress present in the specimen will always be related to mechanical strain components. The ϵ^{vp} generates a permanent deformation that will not generate any mechanical stress. However, the level of viscoplastic deformation reached before the machine stops might influence the mechanical response of the material during cooling.

The calculation of the elastic strain $\epsilon_{T_a}^e$ is shown in Eq.(2), as function of the axial force of the test (F_a), the area of the specimen (A) and the elastic modulus of the material as function of the temperature evaluated at T_a ($E(T)$).

$$\epsilon_{T_a}^e = \frac{F_a}{E(T_a) \cdot A} \quad (2)$$

The thermal strain during Stage 1 is computed as shown in Eq.(3)

$$\epsilon_{T_0 \rightarrow T_a}^{th} = \int_{T_0}^{T_a} \alpha(T) dT \quad (3)$$

Where $\alpha(T)$ is the thermal dilatation coefficient in [$^{\circ}\text{C}^{-1}$].

In **Stage 2**, the creep test is interrupted, the crosshead locked, and the specimen begins a natural cooling down process. Let us step in an intermediate temperature T_b found within the limits ($T_0 \leq T_b < T_a$) as seen in Figure 1. During this stage, the total strain ϵ_2^{tot} is now calculated as the summation of the contributions elastic strain at the previous configuration (ϵ_1^e), thermal strain at the current temperature ($\epsilon_{T_0 \rightarrow T_b}^{th}$), and the prevented thermal expansion strain consequence of the temperature change from T_a to T_b . This relation is expressed in Eq.(4).

$$\epsilon_2^{tot} = \epsilon_1^e - \epsilon_{T_a \rightarrow T_b}^{th} + \epsilon_{T_0 \rightarrow T_b}^{th} = \epsilon_1^e - \int_{T_a}^{T_b} \alpha(T) dT + \int_{T_0}^{T_b} \alpha(T) dT \quad (4)$$

The tensile axial force exhibited by the specimen is produced by the mechanical strain components at stage 2. These are: the elastic strain in the previous configuration (ϵ_1^e) and the thermal contraction of the specimen ($\epsilon_{T_a \rightarrow T_b}^{th}$) that adds into the component. The mechanical strain is calculated as the summation of these components as shown in Eq.(5).

$$\epsilon_2^{mech} = \epsilon_1^e - \int_{T_a}^{T_b} \alpha(T) dT \quad (5)$$

The axial force in the specimen can then be computed as function of the current cooling temperature T_b (from $T_a = 1000^{\circ}\text{C}$) by solving Eq.(6).

$$F(T_b) = E(T_b) \cdot A \cdot \left[\epsilon_{T_a}^e - \int_{T_a}^{T_b} \alpha(T) dT \right] \quad (6)$$

The force function given in Eq.(6) provides an idealistic solution where the following three simplifications are considered: (I) the material behaves elastically throughout the entire cooling path; (II) The possible pre-existing viscoplastic deformation is disregarded; and (III) IDK.0

- I. **Possible material yielding.** The progressively larger deformations generated during the cooling down process of the specimen, in combination with a larger elastic modulus, will result in larger stresses. Because of the high stress level reached during the process, it is highly likely that the specimen could reach a yielding point during cooling. Yielding would entail a non-linear response of the force v/s temperature as the material enters in conventional plasticity.
- II. **Pre-existing inelastic deformations.** Any viscoplastic deformation occurring in the material before the crosshead locks will modify its yielding point, and thus induce a larger axial force during cooling.
- III. **A direct transition between thermal and mechanical strains.** Due to permanent microstructural changes induced after high-temperature exposure, the thermal strains do not directly convert into mechanical strains. The assumption of a direct transformation is therefore non-realistic. The assessment of this point is dismissed for the purpose of simplifying calculations.

Let us first address the yielding of the material (I). This event is set to occur once the specimen reaches the yielding threshold. Following the analytical strain-dependent formulation proposed hereabove, the threshold value will be given by the yielding strain (ϵ_b^y), calculated as function of the current yield stress of the material σ_y , and the elastic modulus E . The latter is expressed as function of temperature ($E(T_b)$), whereas the yield stress is expressed as a function of the current inelastic strain and temperature ($\sigma_y(\epsilon_b^{in}, T_b)$). The yield strain is given in Eq.(8).

$$\epsilon_b^y(\epsilon_b^{in}, T_b) = \frac{\sigma_y(\epsilon_b^{in}, T_b)}{E(T_b)} \quad (7)$$

Let us now address point (II): The inelastic strain during cooling, expressed in Eq.(8), is calculated as the summation of the contributions of the previously built viscoplastic strain (ϵ^{vp} , see Eq.(1)) and the possible new plastic deformations occurring during cooling.

$$\epsilon_b^{in} = \epsilon^{vp} + \epsilon_b^p \quad (8)$$

Finally, the axial force generated in the specimen is calculated as a conditional function depending on three independent variables: the previously built viscoplastic strain ϵ^{vp} , the cooling temperature (T_b) and the geometrical constraints of each specimen (cross section area A for D06 or D10). The function to map the axial force response is given in Eq.(9).

$$F(\epsilon^{vp}, T_b) = \begin{cases} E(T_b) \cdot A \cdot \left[\epsilon_{T_a}^e - \int_{T_a}^{T_b} \alpha(T) dT \right] & \text{if } \left[\epsilon_{T_a}^e - \int_{T_a}^{T_b} \alpha(T) dT \right] \leq \epsilon_b^y(\epsilon_b^{in}, T_b) \\ E(T_b) \cdot A \cdot [\epsilon_b^y(\epsilon_b^{in}, T_b)] & \text{otherwise} \end{cases} \quad (9)$$

2. Application on Incoloy 800H

The resolution of the function described in Eq.(9) for Incoloy 800H is hereafter provided in the form of diagrams where the axial force generated during cooling of the specimen is correlated with the axial force produced by the specimen. To address the effect of the viscoplastic strain reached before the machine malfunction (ϵ^{vp}), different axial force curves are plotted assuming a wide and realistic range of ϵ^{vp} from 0 up to 0.4.

To assess the level of axial force generated in relation with the maximum admissible load supported by the installed 10 kN load cell, a color code scale is introduced alongside the axial force axis in each diagram. The color code is defined in Table 1.

Table 1: Color code indicating the risk level of our load cell in relation with the applied force.

Color	Range (kN)	Description in relation with our 10kN load cell
Red	>30	Danger. The load cell is not rated to withstand forces falling within this range.
Orange	15-30	Caution. The load cell cannot measure but can withstand forces of up to 300% over its nominal force. Upon reaching this threshold, zero offset may be lost.
Yellow	10-15	Caution. The load cell cannot measure but can withstand forces of up to 300% over its nominal force.
Green	0-10	OK. The load cell is designed to measure axial forces within this range.

Results for specimens D06 are given in Figure 2 for cases of creep test at 5 and 50 MPa.

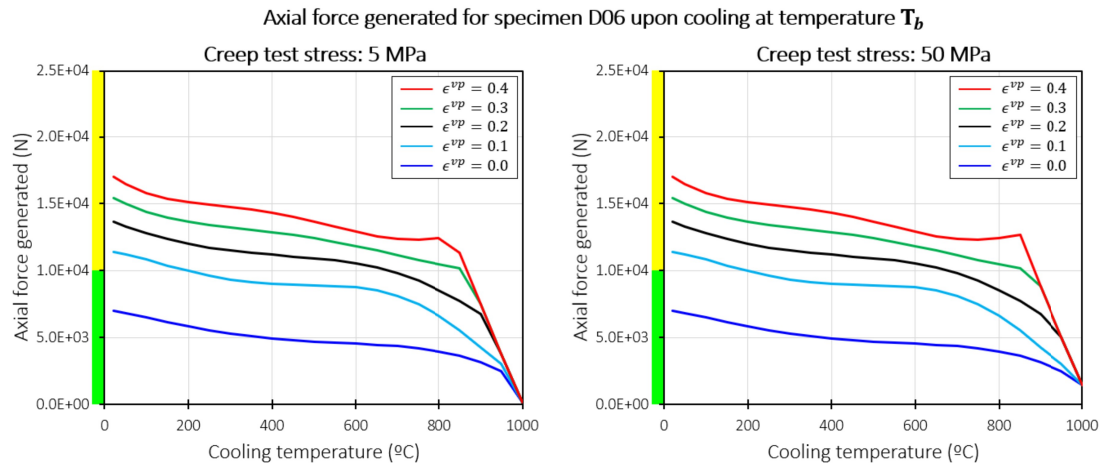


Figure 2: Diagram describing the generated axial force during cooling of specimens D06 after cooling down from a creep test at 1000°C and stresses of 5 or 50 MPa.

Results for specimens D06 are given in Figure 3 for cases of creep test at 5 and 50 MPa.

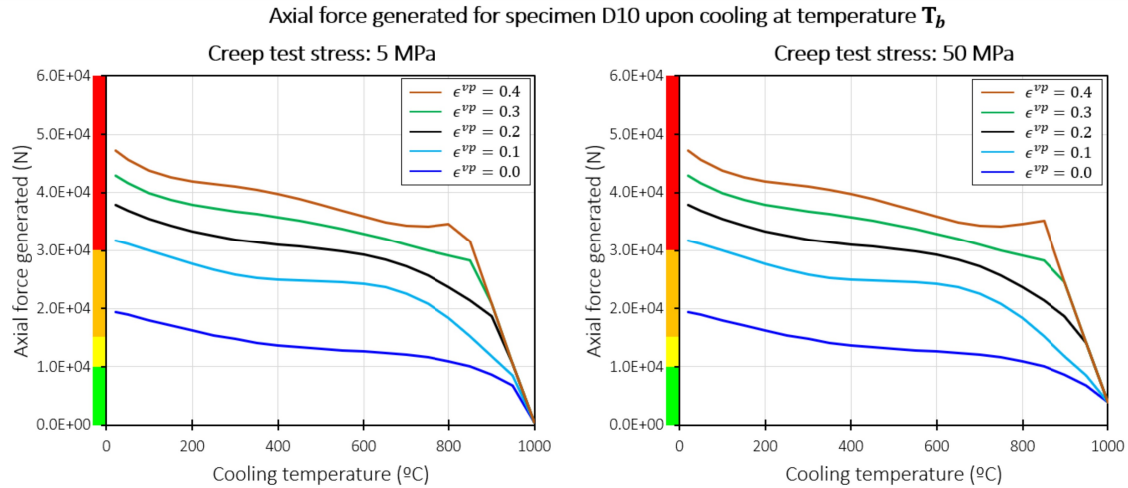


Figure 3: Diagram describing the generated axial force during cooling of specimens D10 after cooling down from a creep test at 1000°C and stresses of 5 or 50 MPa.

3. Concluding remarks

In this short report, an analytical study on the axial loads produced during cooling after a worst case-scenario creep test interruption has been conducted. The results show that:

- The difference in the axial force response attributed to the stress of the creep test is only noticeable at the beginning of the cooling process. Compared with the thermal effects, the stress at which the test was conducted has a negligible impact on the axial forces produced during cooling.
- Upon cooling with a locked crosshead, the nominal force of the 10 kN load cell is surpassed by both specimens in all realistic scenarios (i.e., non-zero viscoplastic strain).
- The axial forces generated by specimens of geometry D06 are found well below the force levels associated with mechanical damage of the 10 kN load cell. A worst-case scenario creep test interruption with this load cell, this material and this geometry is therefore considered low risk.
- The axial forces generated by specimens of geometry D10 are found dangerously close and above the force levels associated with mechanical damage of the 10 kN load cell. A worst-case scenario creep test interruption with these load cells, this material and this geometry is therefore considered of high risk.