Schleibinger ASTM C1581 Shrinkage-Ring

Schleibinger Geräte
Teubert u. Greim GmbH
Gewerbestraße 4
84428 Buchbach
Germany
Tel. +49 8086 94010
Fax. +49 8086 94014
www.schleibinger.com
info@schleibinger.com

February 15, 2017

Contents

1 Introduction

All mortars are changing their volume from the moment the binder particles came in contact with water until several months and years. In most practical application this expansion and shrinkage must be minimized. Many theoretical models are describing the cause of this effects, but specially the mechanism in the first hours are not completely understood yet. One demanding prerequisite for controlling the shrinkage of mortars are measurement instruments that are able to measure shrinkage and expansion from the early beginning of hydration and setups that are able to simulate environmental conditions in the field application.

Up to now shrinkage and expansion of building materials is measured by simple mechanical instruments like cantilevers. Therefore a certain strength of the material is necessary.

There is a survey given about more modern sensors and instruments measuring also the early shrinkage before the setting point. Beneath others a contactless LASER based measurement method with a coneformed formwork is presented avoiding the problems shown above.

1.1 Taxonomy of Shrinkage Measurement Systems

As long as a material is in the fluid state shrinkage is not causing a problem. The only thing you have to keep in mind is, that a length change on each site of a 1 cubicmeter cube of 1/1000 is already a volume change of about 3 liters.

When the material is setting and/or is in contact with a material that has no shrinkage or expansion, strain inside the material or in the contact zone will appear. As soon as this tension will be over the actual tensile strength of the material, the material structure will be damaged, usually by the occurring of cracks.

Therefore its obvious not only to measure the free shrinkage but also the strain that occur. It's called measurement of the blocked or restrained shrinkage. The tensile strength and the materials volume is changing most in the first hours after mixing, so restrained and free shrinkage should be observed as early as possible in the hydration process.

The process of crystal grow itself is influenced by the environmental conditions like temperature, humidity, freeze thaw cycles, penetration of gas, or salty or acid liquids. This environment must be kept constant to detect the shrinkage of the material itself. But on the opposite the length change may be an indicator for the resistance against an environmental attack on the material. For example for detecting the alkali silica reaction or for indicating the freeze/thaw resistance of concrete.

Figure 1 shows free shrinkage over the time in a general way. We must distinguish 3 ranges of of material strength for using different measurement techniques:

- fluid (F)
- starting of setting (S)
- hardened material (H)

These 3 ranges may be subdivided depending on the material geometry and environmental conditions. For example:

- rigid volume, no evaporation

- low volume, high surface, high evaporation
- high or low temperature
- periodical temperature changes
- humidity gradient
- temperature gradient

The appropriate shrinkage measurement instruments are also shown.

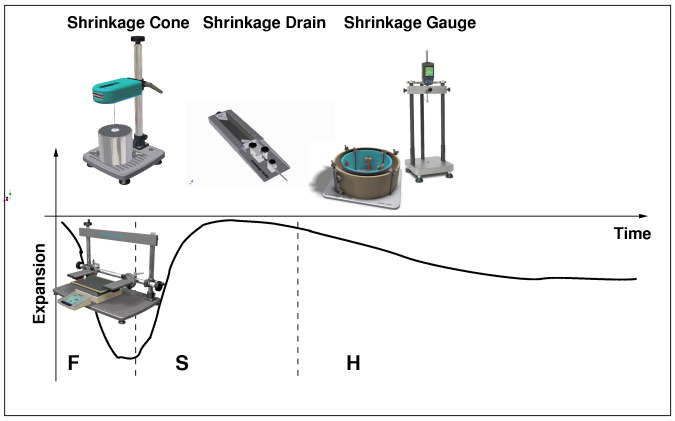

Figure 1: Shrinkage over time

Schleibinger is offering the whole range for measuring shrinkage of constructing materials.

- The Schleibinger Shrinkage-Cone and the Schleibinger Thin - Layer - Measurement System are the ideal instrument for measuring the very early shrinkage and expansion of building materials like paste, mortar, plaster etc. A toucheless laser sensor allows data acquisition suddenly after filling the cone-formed specimen container or the thin layer formwork.
- The Schleibinger Shrinkage Drains are working in a similar way. Here the shrinkage or expansion is measured with a movable anchor .
- The Schleibinger Bending Drain measures not only the length change, but also the curling of the specimen. Here also the influence of floor heating is simulated.
- The Schleibinger Shrinkage Ring according to ASTM C1581 is measuring the forces occurring at restrained shrinkage.

2 Theory of Operation

2.1 Measuring Restrained Shrinkage

Measuring blocked or restrained shrinkage is not an easy task.

Such a system could be realized for example by an active controlled mechanical structure, where a hydraulic ram compensates each movement and the the forces are measured indirectly over the hydraulic pressure. Such systems have been realized [5] but the technical and the economical expense is quite high.

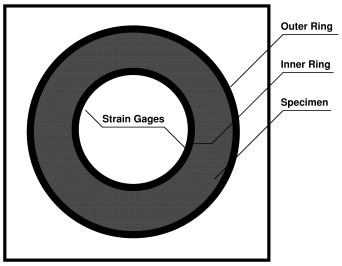

Figure 2: Shrinkage Ring

The standard ASTM C 1581 “Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage” [2] is describing a more simple setup. The material is placed between two concentric steel rings. The outer ring has an inner diameter of 406 mm the inner ring an outside diameter of 330 mm. So the specimen is like a donut with 38 mm thickness. The inner steel ring has a wall thickness of 13 mm with strain gages applied for measuring forces (see figure 2). As mentioned before strain gage is basically not measuring forces but even also a length change.

A typical strain of 100 µm/m is an absolute length change at the given geometry of about 116 µm. So shrinkage is only partly restrained.

The inner ring is made of steel 1.0553, formerly as known as steel ST52-3 S355 J0. The Youngs modulus of steel is about 200 GPa/m^2.

2.2 The Schleibinger ASTM Shrinkage-Ring

This test method covers the laboratory determination of the age at cracking and induced tensile stress characteristics of mortar or concrete specimens under restrained shrinkage. The procedure can be used to determine the effects of variations in the proportions and material properties of mortar or concrete on cracking due to both drying shrinkage and deformations caused by autogenous shrinkage and heat of hydration. This test method is not intended for expansive materials.

A sample of freshly mixed mortar or concrete is compacted in a circular mold around an instrumented steel ring. The compressive strain developed in the steel ring caused by shrinkage of the mortar or concrete specimen is measured from the time of casting.

The Schleibinger Shrinkage-Ring has 4 sets of strain gages applied. Thermal and asymmetric loads are compensated by the geometry used. The amplifier and digitizing unit is directly mounted on the steel ring. Several of the Shrinkage rings maybe connected to one single data logger delivered with the Shrinkage Ring.

Cracking of the test specimen is indicated by a sudden decrease in the steel ring strain. The age at cracking and the rate of tensile stress development in the test specimen are indicators of the material?s resistance to cracking under restrained shrinkage.

This test method is applicable to mixtures with aggregates of 13-mm maximum nominal size or less.

This test method is useful for determining the relative likelihood of early-age cracking of different cementitious mixtures and for aiding in the selection of cement-based materials that are less likely to crack under

retrained shrinkage. Actual cracking tendency in service depends on many variables including type of structure, degree of restraint, rate of property development, construction and curing methods, and environmental conditions.

This test method can be used to determine the relative effects of material variations on induced tensile stresses and cracking potential. These variations can include, but are not limited to, aggregate source, aggregate gradation, cement type, cement content, water content, supplementary cementing materials, or chemical admixtures. For materials that have not cracked during the test, the rate of tensile stress development at the time the test is terminated provides a basis for comparison of the materials. [1]

3 Handling

3.1 Shrinkage Ring

You may see the complete assembling in Figure 3, 5 and 7.

- First set the steel ring with the strain gages onto the base plate.
- Center the inner ring with the 3 turnbuckles. Open the and close the turnbuckles with the red crank. The turnbuckle is fixed in the lower position of the crank.
- Coat the outer surface of the inner steel ring with a release agent.
- Coat the inner surface of the outer ring with a release agent.
- Screw the four threaded bars including the jackets to fix the inner ring on the base plate.
- Set the outer stainless ring onto the base plate. Close the outer ring with two quick releases figure 7.
- Fix the outer ring with the 2 turnbuckles in the same way as the inner ring. See picture 5
- Lay the green steel beam on both rings and fix the beam with the two threaded rods.
- Place the test specimen mold on a vibrating table, fill the mold in two approximately equal layers, rod each layer 75 times using a 10-mm diameter rod, and vibrate each layer to consolidate the mixture.
- Strike-off the test specimen surface after consolidation. Finish with the minimum manipulation necessary to achieve a flat surface. Remove any fresh concrete or mortar that has spilled inside the steel ring or outside the outer ring so that the base is clean.
- Transfer the test specimens to the testing environment within 10 minutes after completion of casting.
- Upon transfer of the test specimens to the testing environment, immediately loosen the turnbuckles and the butterfly nuts so they are not in contact with the steel ring and outer ring anymore
- Within 2 minutes after loosening the bolts and turnbuckles, connect the strain gage amplifier with the data logger (orange cable) to the data acquisition system, record the time, and begin monitoring the strain gages at intervals not greater than 30 minutes.

[1] Parts of the text in chapter 2.2 are cited from the ASTM C1581 standard

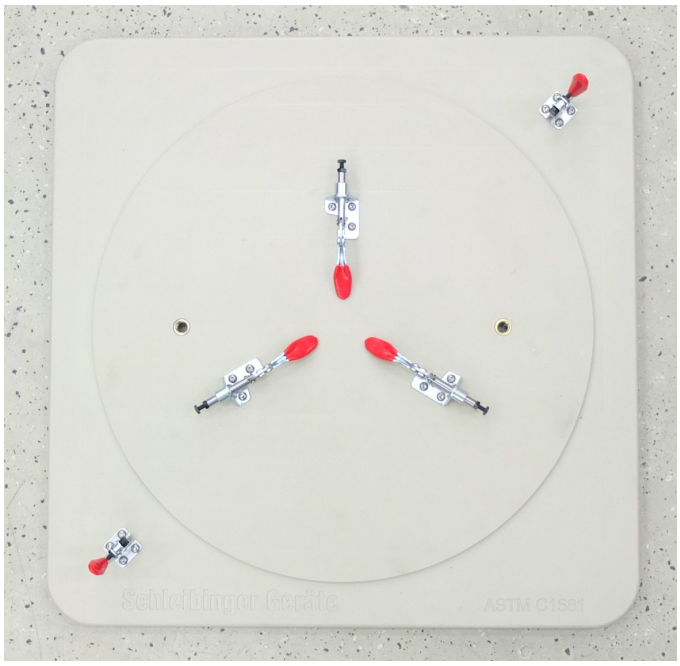

Figure 3: Base plate of the Schleibinger Shrinkage-Ring, shown from the top

- Ensure that the strain gage connecting wires are clean of loose material before making the connections. The time of the first strain measurement is taken as zero age of the specimen.
- Start the measurement.
- You may cover the specimen with the stainless steel lid included instead of the aluminum or PE foil recommended by the standard. See figure **??**
- After setting the outer ring should be removed.

4 Hardware Installation

4.1 Requirements

The shrinkage-cone, the TLMS, the bending drain, the shrinkage drain and the shrinkage ring are delivered with a data-logger. The data logger records the measurement values more then 40 weeks autonomous. The data-sets are stored non-volatile in the data-logger. The logger is equipped with a network interface. It may be integrated in your local intra-net as well as into the world-wide Internet. As user interface you need a PC with an actual Internet browser software like (Firefox 24+, Internet Explorer 9+, Microsoft Edge, Chrome 25+, Opera 15+, ...). You can use any PC from Win95..Windows10 as well as Linux ore MacOS. Even a tablet running Android or iOs is possible. The PC must be equipped with an Ethernet network interface running the TCP/IP protocol. The data-logger need a free fix IP address, but also activating a DHCP service is possible. For using it without a network, take a cross-wired Ethernet cable (Cat5, RJ45) During the measurement you need no running PC. The configuration is described in detail in section 5.

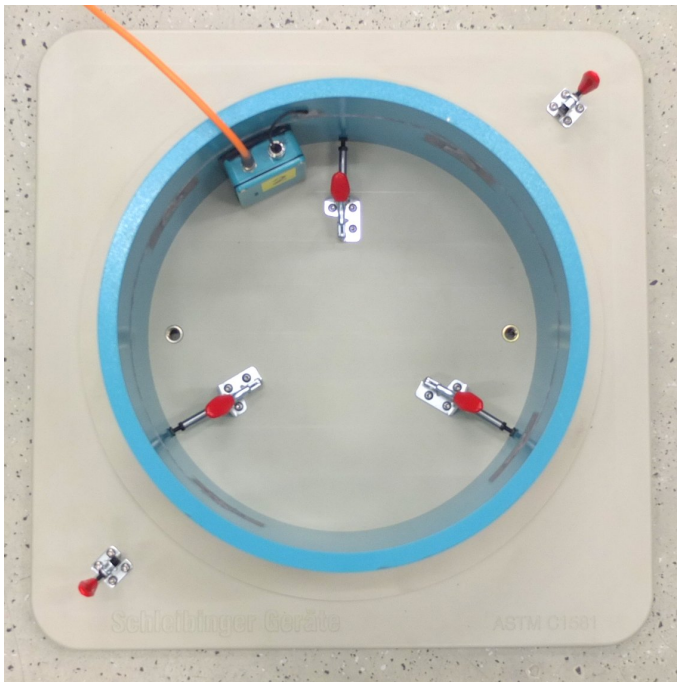

Figure 4: Center the inner ring with 3 turnbuckles

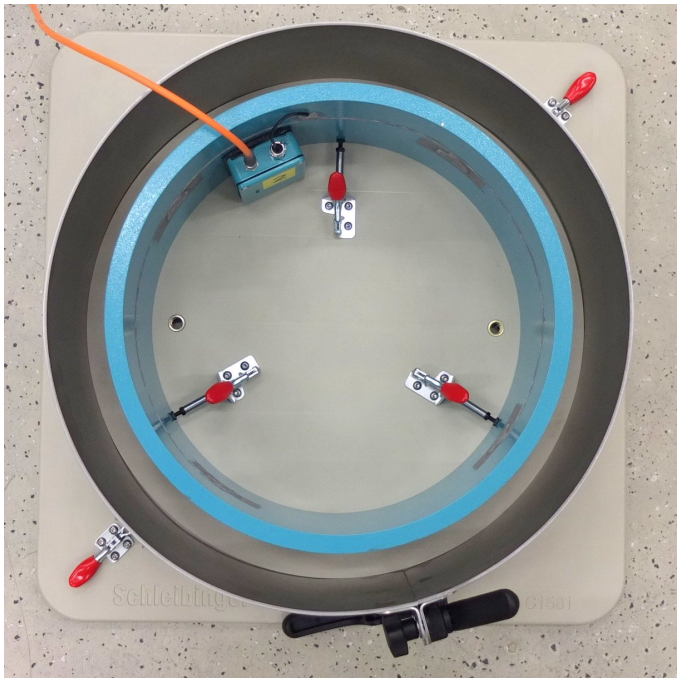

Figure 5: Fixing the outer ring with the 2 outer turnbuckles

Figure 6: The quickreleases of the outer ring in the released position

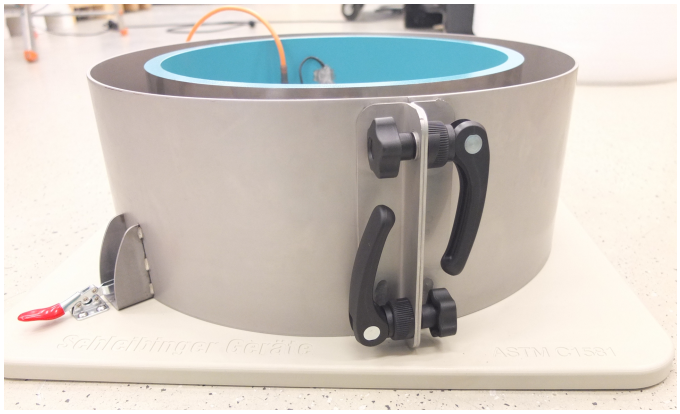

Figure 7: The outer ring closed.

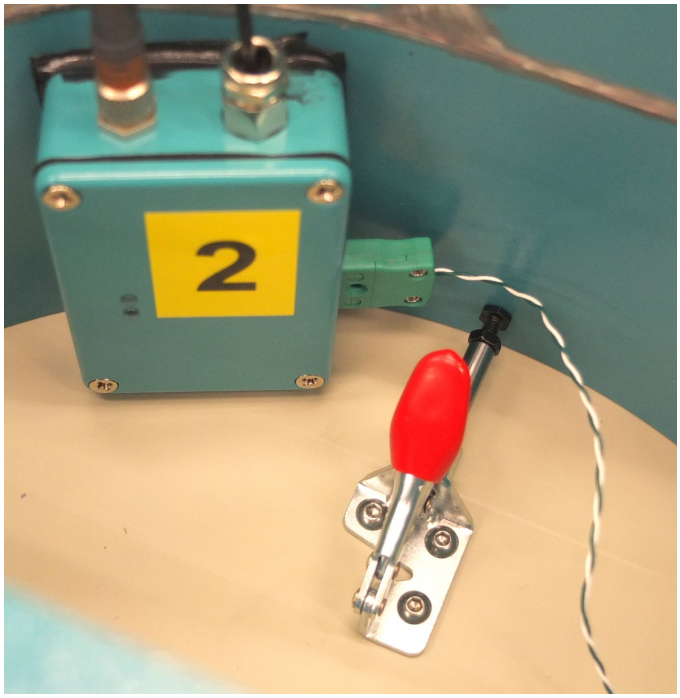

Figure 8: Connect the type K thermocouple .

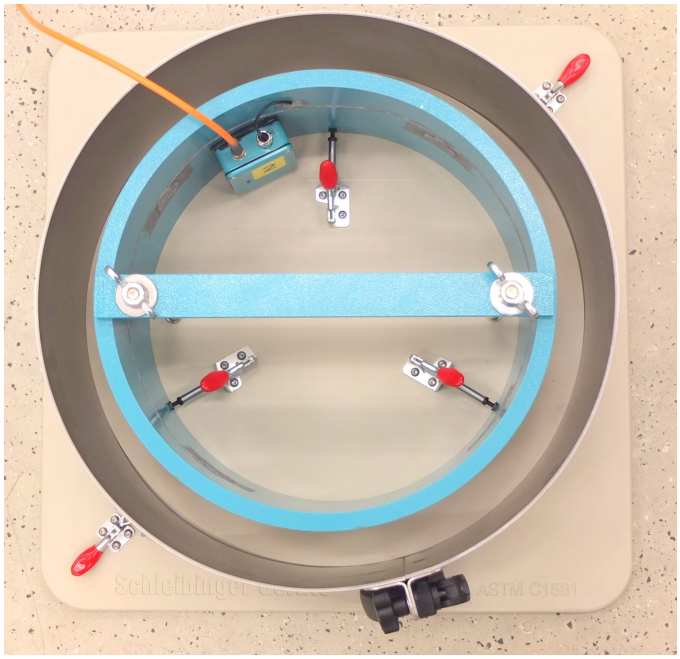

Figure 9: Fix the inner ring additional on the base plate with the green steel bar and 2 threaded rods with butterfly nuts.

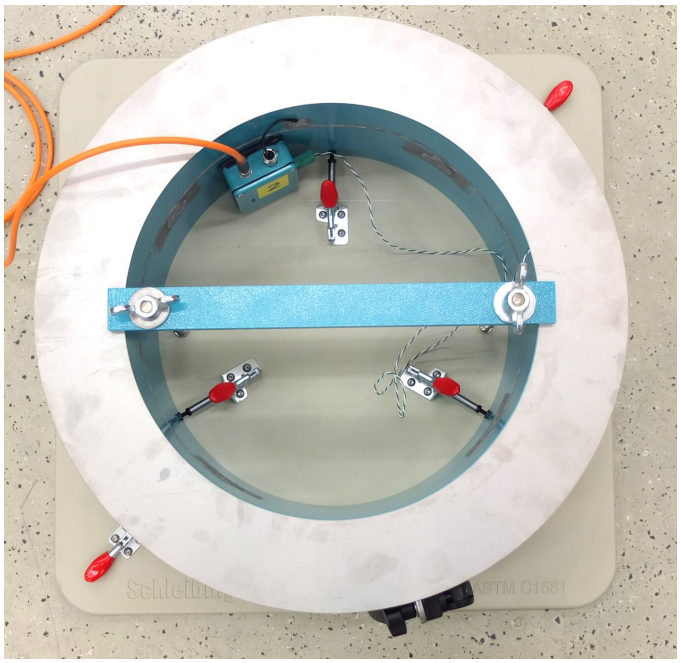

Figure 10: You may cover the concrete with the stainless steel or plastic foil.

Beneath the http protocol you may also readout the data with the file-transfer protocol (ftp). The username for the ftp protocol is `ftp`, the pasword also `ftp`.

For debugging purposes you may also login with the telnet protocol. Here username and password are `tel`.

4.2 Installation of the Data-Logger for the Shrinkage-Ring

- The data-logger will be delivered with a 100V-240V ~, 50..60Hz power supply. Connect the power supply with the 3 pin DIN plug to the data logger. After some seconds the data logger is running and the LED indicator should blink.
- Connect the 25-pin D-Sub connector with the orange cable to the data-logger. (figure 11). Connect the M8 connector to the strain gage amplifier mounted at the green steel ring. Fix the screw of the connector only by hand. Don't take a gripper.
- The straingage and thermocouple amplifier is identified electronically. You may connect the amplifiers to the data logger in any order.
- Connect the optional temperature/humidity sensor to the connectors on the backside of the logger.
- The network cable is connected to the RJ45 plug on the front side of the data logger. Configure the network interface as described in chapter 5.
- The data-logger requires a free IP address. The logger is delivered with the address 192.168.1.40. Please use the Windows-program Chiptool.exe (delivered with the data-logger) to change the IP address

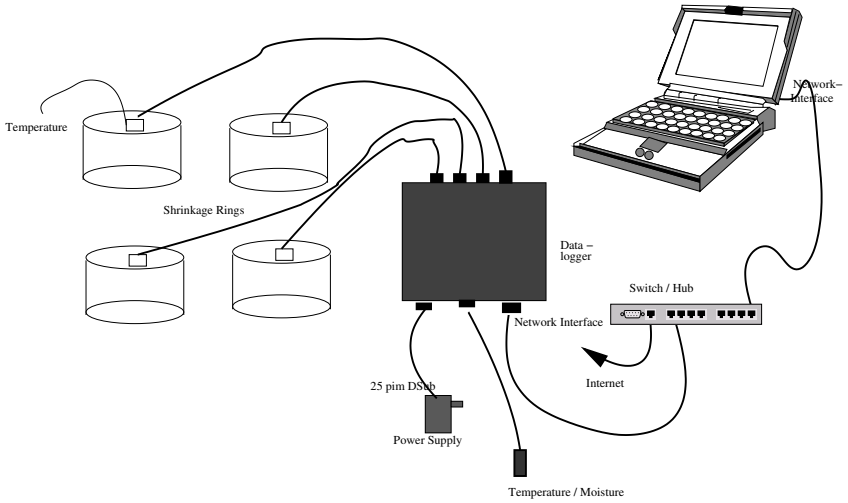

Figure 11: Wiring the shrinkage rings

4.3 Thermocouples

As option thermocouples may be connected to the data-logger or the strain gage amplifier of the Shrinkage Rings for measuring the specimen temperature.

A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots, where a temperature differential is experienced by the different conductors (or semiconductors). It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit. Thermocouples are a widely used type of temperature sensor for measurement and control. Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve.

Please use only Type K thermocouples with the Schleibinger data logger. Otherwise you will get wrong results!

There are different types of thermocouples on the market. Type K (chromel / alumel) is the most common general purpose thermocouple with a sensitivity of approximately $41\mu V/C$ (chromel positive relative to alumel when the junction temperature is higher than the reference temperature). It is inexpensive, and a wide variety of probes are available in its -200 °C to +1350 °C range.[2]

After the measurement you may simply pull out the thermocouple from the specimen. If its not possible cut it off. You may reuse it by removing the insulation at the cable head and drill the both cables with several windings together again.

[2] Text partly from: Wikipedia contributors. "Thermocouple." Wikipedia, The Free Encyclopedia. Wikipedia, The Free Encyclopedia, 31 May. 2015. Web. 5 Jun. 2015.

5 Configuring the Network access

The Schleibinger data logger, the Slabtester and the CDF machine are equipped with a *100 BaseT* network interface. It can be integrated within a local Intranet or globally into the Internet. The network configuration can be done with the program Chiptool (it can be found at the product CD-ROM delivered with the equipment, sub directory Beck-chiptool).

Example Default Settings:

```
Device: Data logger for the shrinkage cone
Customer:  Miximaxi AG
Serial Nr: 201312324
MAC-ID: 00:30:56:90:7D:C3
Hostname: Scone_201312324
[]   Obtain an IP-Address automatically
[]   Use the following IP-Addresse: IP addresse:.......
Subnet mask:.......
```

5.1 How to do the network configuration between the data logger and a PC

You have two options, below described number 1 is the one set by default - obtain an IP-Address automatically.

5.1.1 Working with a symbolic Server Name

Connection of the data logger into a local network with DHCP- and DNS-Server is the simplest and fasted method.

- Connect the data logger with your local network (switch) using the network cable which was delivered with the device and switch on the data logger (24V adapter)
- Enter the host name into the address line of your browser - see symbol 1 in screenshot 12 (see default settings)

Figure 12: Accessing the data logger with a symbolic server name

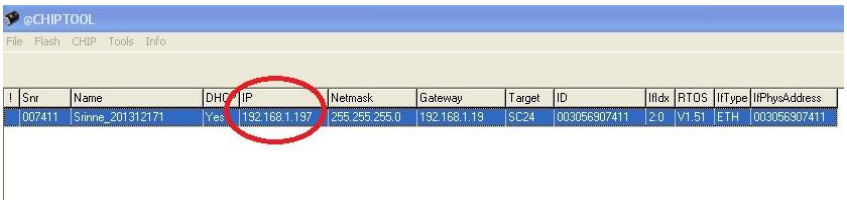

Figure 13: Readout the IP address to the data logger with the program chiptool

Figure 14: Accessing the data logger with a fix IP address

A DHCP-Server assigns a free IP address to the data logger. You can access the data logger via the default host name using the DNS - see picture 12.

Hint: DHCP server are scanning the network from time to time assigning a IP address and a symbolic name to all computers in the network. This procedure may last some time. So please wait some minutes until you try to access the data logger with its symbolic name.

5.1.2 Working with a fix IP address

If the hostname-method/DNS-server doesn't work or supported in your network, you can access the data logger via the assigned IP address. You can determine the IP address of the data logger with the above mentioned program chiptool.

Your network administrator has to make sure that the data logger always gets the same IP address from the DHCP server. Into the address line of your browser you enter the IP address assigned by the DHCP server instead of the host name. See figure.

If there is no network or you are not allowed to connect a measurement device into your local network, you can connect the Schleibinger data logger directly to a PC, e.g. with an older notebook. Most of the PCs are configured in a way, that they take an IP address automatically assigned by the DHCP server. In case of a direct connection between data logger and PC, both peers are missing the DHCP server. You have to use static IP addresses in this case.

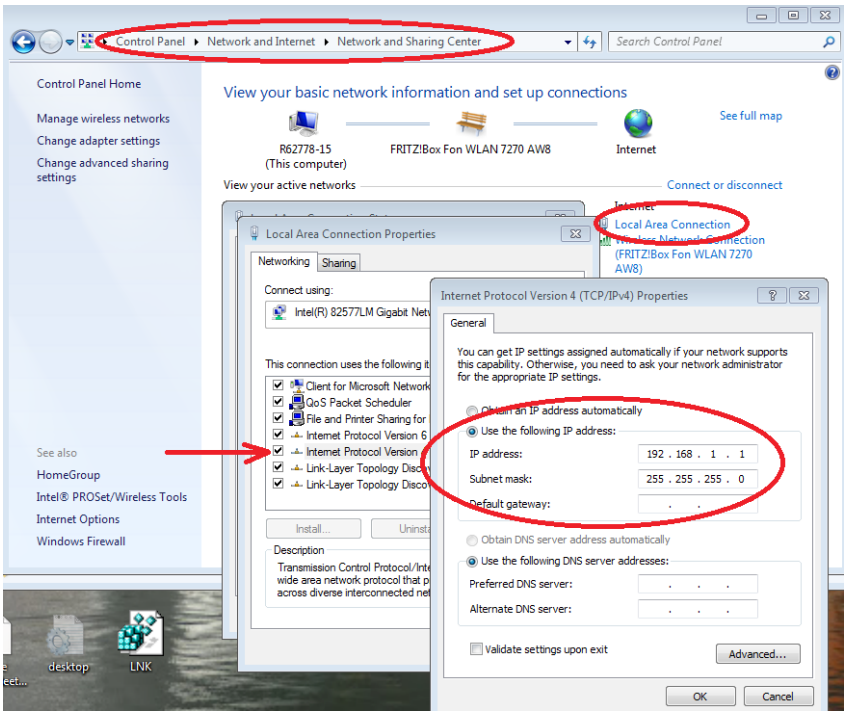

Figure 15: Configuring the PC for a direct connection between the PC and the data logger

5.2 Setting a static IP-address on a Windows computer

Open `Control Panel` → `Network and Internet` → `LAN-Connection` → `Properties` and set a static IP-address from the so called private area e.g. `192.168.1.1` and a sub net mask `255.255.255.0`. Gateway doesn't has to be set. See figure 15

5.3 Setting a static IP address on the data logger

Connect the data logger and the PC where you have just set the static IP address. The best with a cross-wired Ethernet cable (Cat5, RJ45)- not delivered with the equipment, and start the program chiptool. The program is searching for the data logger and if the PC is configured correctly and the right connection cable is used, appears the Schleibinger device in the window of the program. Click with the right mouse button on the entry within the window and chose IP configuration. A little window appears. Set a static IP address from the same private area as well (but different to the one on the PC) e.g. `192.168.1.2` and the same sub net mask. Finally click on `Config`.

If you enter the just set IP address of the data logger into the address line of your browser, the main page of the data logger should appear.

Please ask your network administrator how to integrate best the data logger into the network infrastructure.

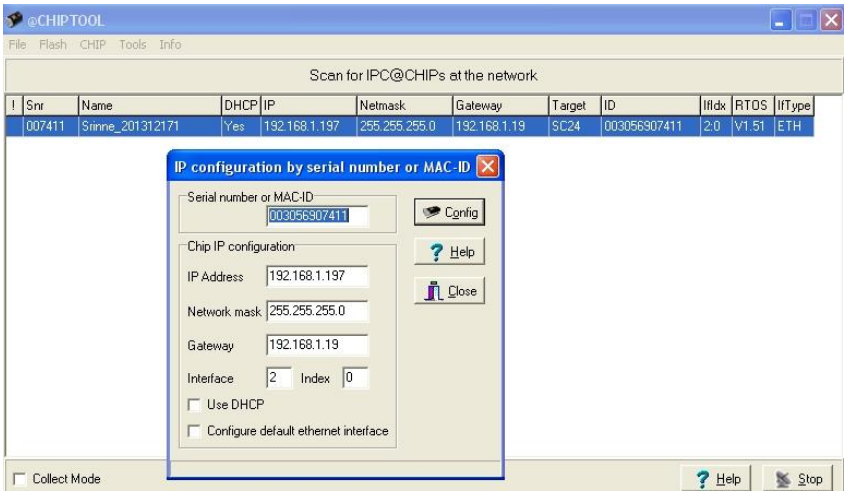

Figure 16: Configuring the data logger for a direct connection between the PC and the data logge with the program chiptool

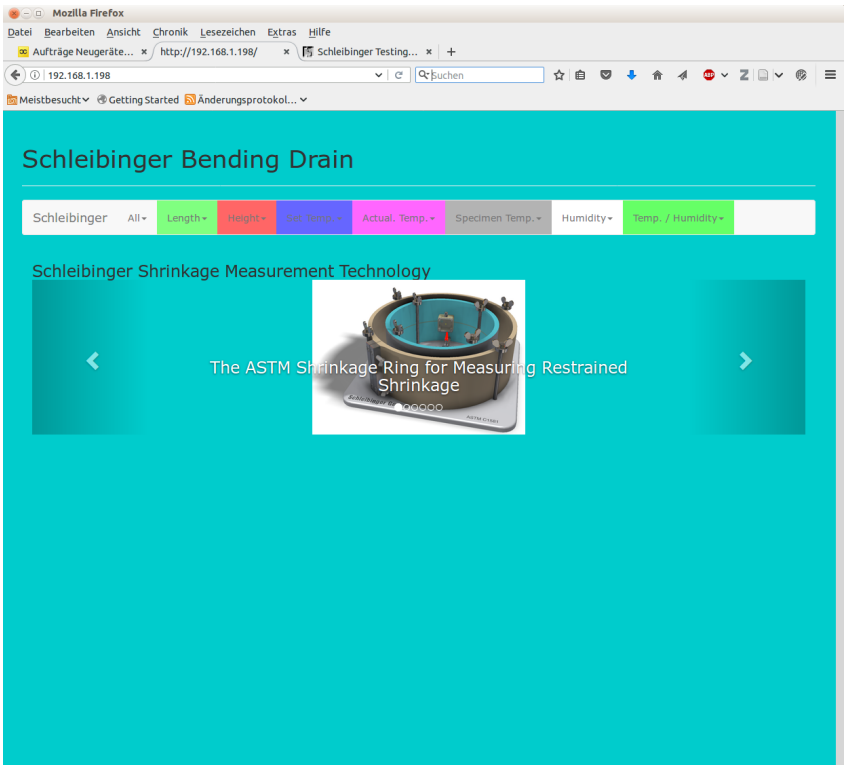

Figure 17: Start screen

6 The Software

The software is quite similar for all four shrinkage test systems.

6.1 Recording Data

As soon the data-logger get power, data acquisition starts. This is shown by the blinking LED at the front-side of the data-logger. The PC is only required for setup and data transfer.

6.2 Software Handling with your Web-Browser-Software

To communicate with the data logger start at your PC your web browser software. Input at the address line the IP address of your data logger for example 192.168.1.40

The following start screen will appear in your browser (fig.: 17).

In the header you see on the left the drop down menu `All`. In this menu you may control all things regarding all channels in the same way. For example starting the measurement, set up of the real time clock, showing all data numerical and graphical.

All other drop down menus right of the `All` menu are concerned with each single channels, like the LVDT's, Temperature sensors etc. Depending on the installed options this may be varying (see fig. 18).

Starting a measurement works as follows:

Select your channel in the header-line.

Fill the concrete into the circular mold. Check this by displaying the raw values with:

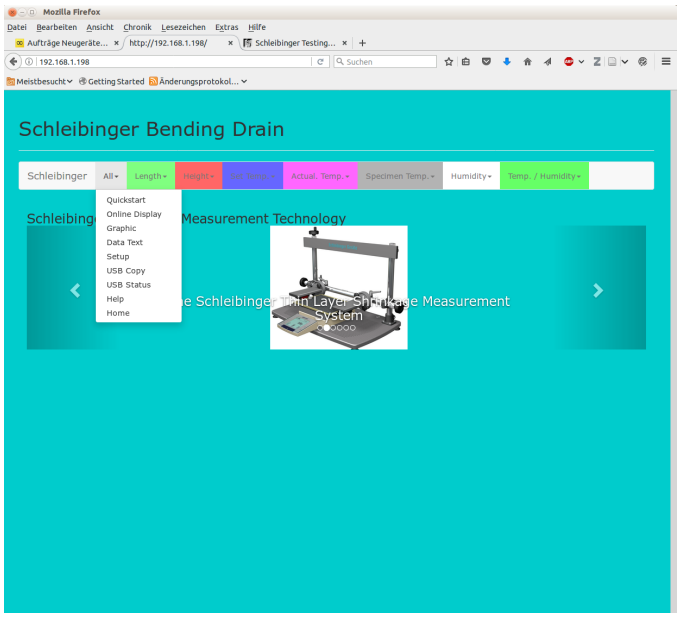

Figure 18: Main menu

`All -> Online Display -> Start.`

The raw value may be anywhere between +2.0 to -5.0. (figure 19)

When starting the measurement as described in the following text, this value is automatically to zero. For starting the measurement we recommend the Quickstart as described in chapter 6.3

Now go to `Offset` and then press the button `Offset=0` . The actual value is set to zero (fig.20).

Now go to `Measurement Start`. Optional you can give a name to the measurement, pressing `Start` resets the time counter to zero and starts recording. (fig.21)

Now go to `Measurement Data-Reset`. All old records will be cleared. (fig.22)

6.3 Quickstart

Quickstart is a comprehension of the point Data-Reset, Offset-Zero and Measurement Start. All these commands are integrated for all channels in the quickstart option.

Attention: All data of all channels will be erased!

6.4 Transferring the datasets

The measurement will be stored locally in the data-logger. The memory is non-volatile.

The easiest way for data transfer to the PC is your web-browser software.

6.4.1 Data Text

Go to `Data Text`. In the right browser window all measurement values will be displayed (fig. 24). In the first column you see the seconds, in the second one you see the measurement values. All columns are separated by tabs.

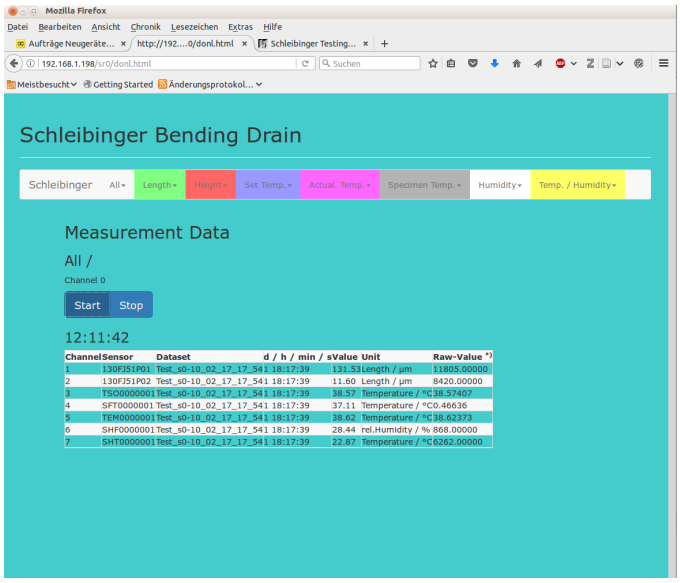

Figure 19: Measurement values in a numerical format

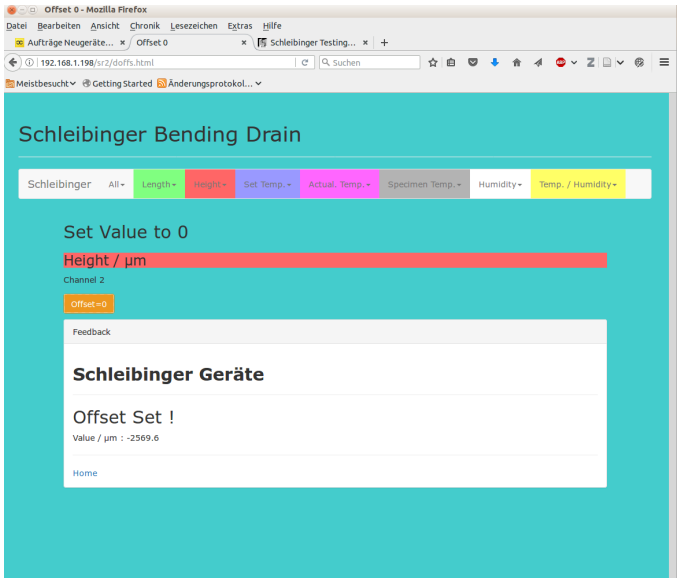

Figure 20: Offset zero

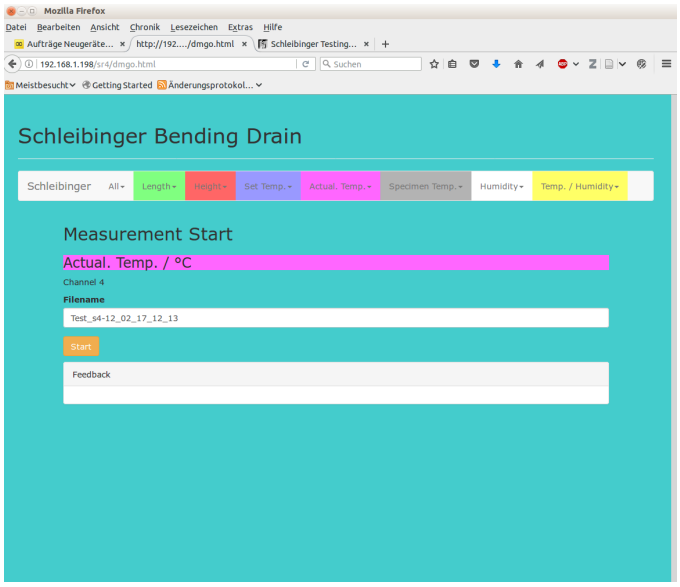

Figure 21: Measurement start

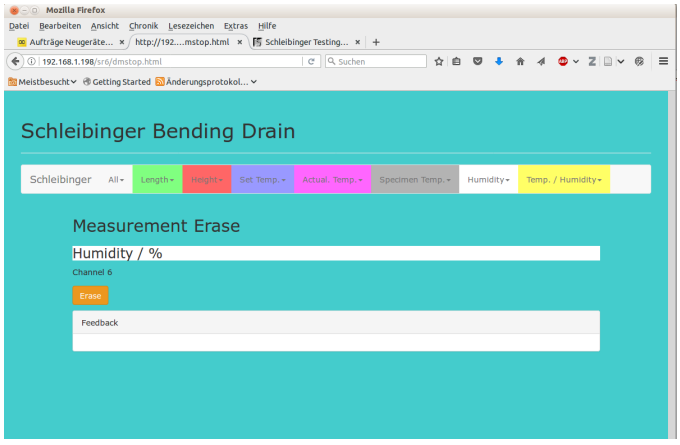

Figure 22: Clear dataset

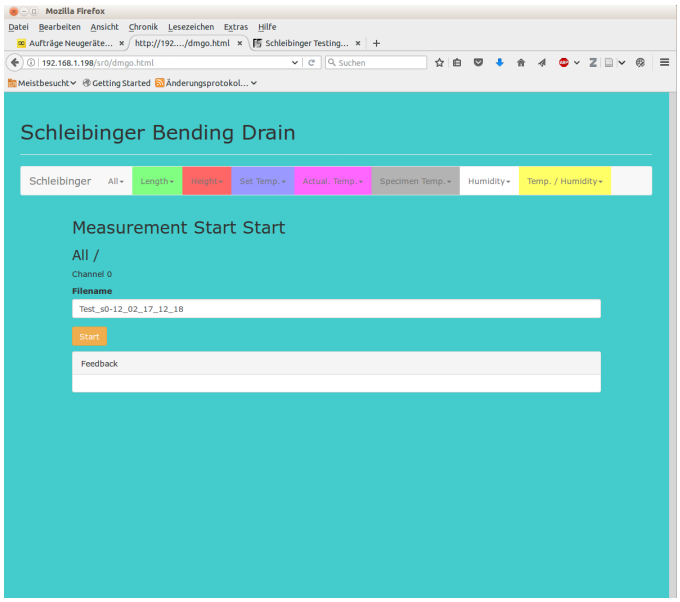

Figure 23: Quickstart

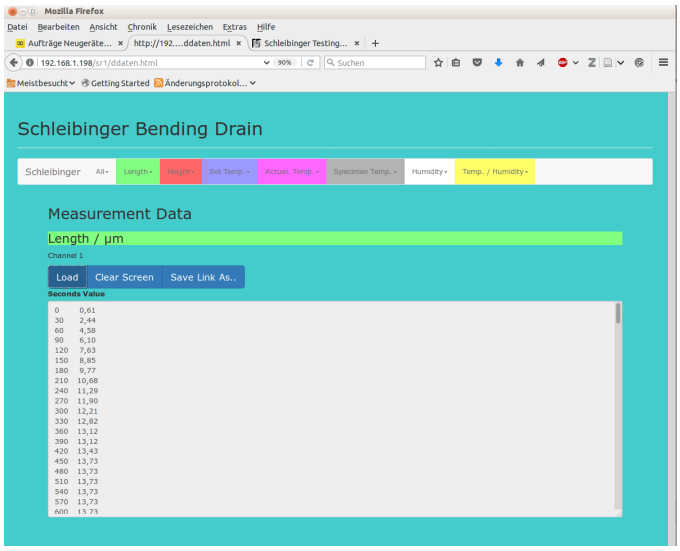

Figure 24: Measurement values as text file

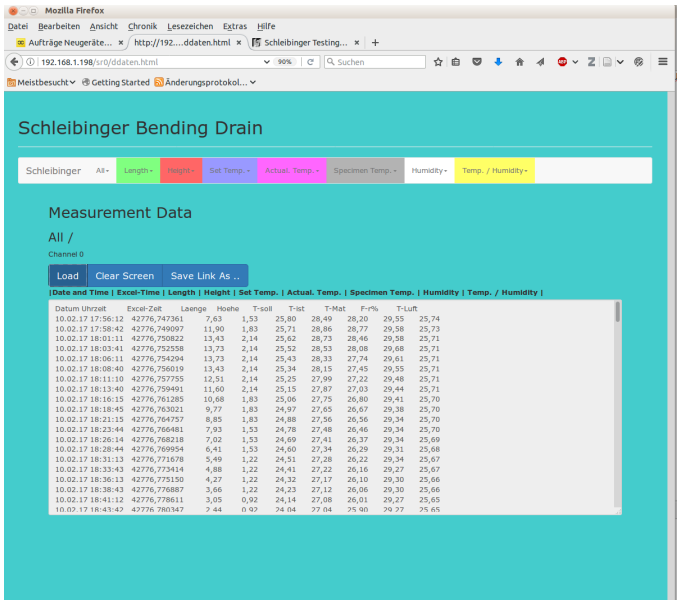

Figure 25: All channels values as text file

From this window you can copy the data to other programs like Excel using the clipboard. You may also directly open this file from your Excel program. Say in Excel `File Open` as filename us

`http://192.168.1.40/daten/data1.txt`

for the first channel `data2.txt` for the 2nd channel and so on.

6.4.2 All Channels

Here a synoptic set of all data channels is stored. The format is as follows:

Date	Time	Excel-Time	Channel 1	Channel 2
12.08.04	10:40:32	38211,444815	3999,6	-221,0

The Excel Time is the internal Excel time format. The digits before the comma show the number of days since January, 1st, 1900. The digits after the comma show the fractal part of one day. For example noon is 0.50000, 6 am is 0.2500. If you import a data set into Excel, you can format this column as date and time and you will see the correct date and time format in Excel. You may retrieve this file directly from Excel at the address

`http://192.168.1.40/daten/data0.txt`

There is a header written in the first data line. If you don't like this, or Excel has problems with the header, erase the file `pheader.txt` in the `par` subdirectory

6.4.3 FTP

The power user can also use FTP for data transfer. Login name is `ftp`, password is also `ftp` The datasets are in `/httpd/htdocs/daten`. Don't use the Internet-Explorer for this. Its is not according to the ftp standard. We recommend Filezilla (free software), wise-ftp ore similar programs.

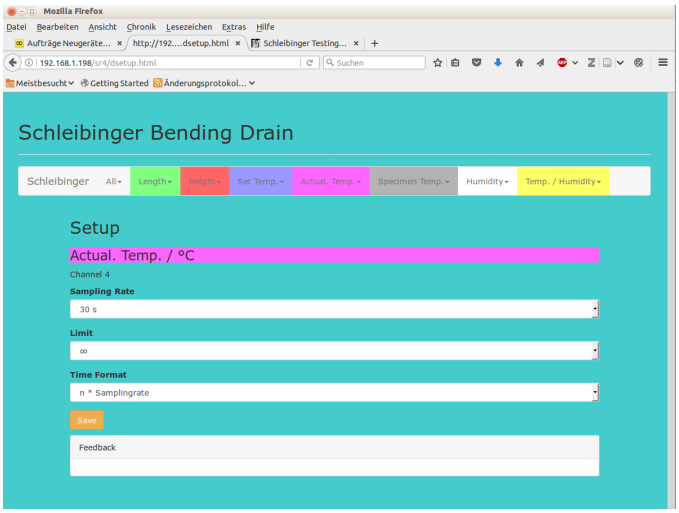

Figure 26: System setup

6.5 Channel Setup

Here you can configure some things.

You can select the sampling rate between 10s and 10 min. (see figure 28)

If you define a limit smaller then $\inf$ then a new value will be recorded if the difference to the last value is bigger then the defined limit ore if the sample intervals is reached. This setup is specific for each single channel.

If you define a sampling rate of for example 30s, the data logger will record data at: 30s, 61s, 90s, 119s . . . The reason for this jitter are small deviations in the response time of the several software processes running on this small computer. If you don't like this in your Excel worksheet please select hier `n*smaplingrate/s` otherwise slect `Time/s`.

6.5.1 All Setup

Here you can setup date and time. The displayed value is only a dummy value. Be careful, the European time format is used.

day.month.year:hour:min for example `26.03.03:12:11`. The hour format is from 0..24h. Press the `Set Date and Time` button as confirmation.

6.6 Online-Data Graphical

You can display several channels in the same plot. In the next chapters you will find a more detailed explanation of this part of the program.

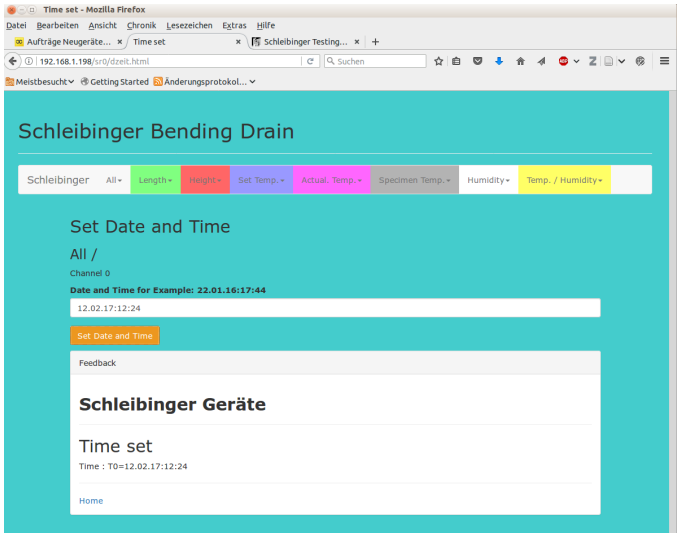

Figure 27: Setup of date and time

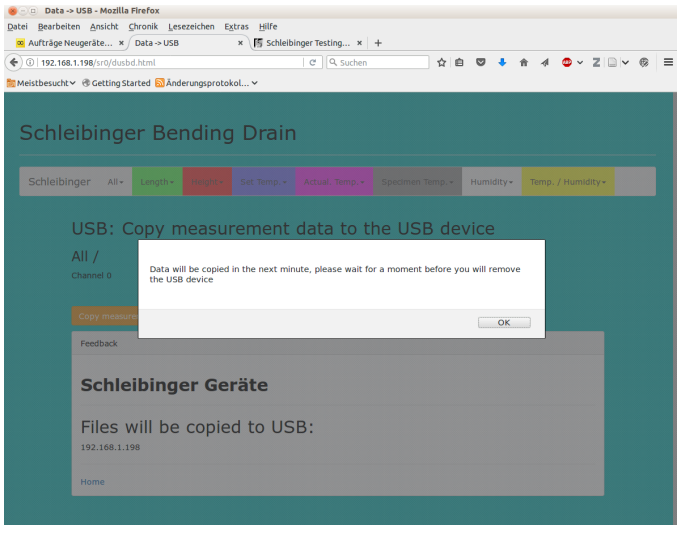

Figure 28: Copiing the measurement data to the USB device

7 Plotting the Measurement Data in HTML5

The software is offering tow options to disply the the measurement data in a graphical way.

The first option is using a so called Java Applet. This is a small program, written in the Java programming language. To run such a program a Java Plugin must be installed in your Internet browser.

7.1 Browser Compatibility

Another option is using the new features offered by HTML5 Therefore you need a new browser software version like the Internet Explorer 9+, Firefox 2.x+, Safari 3.0+, Opera 9.5+ or Konqueror 4.x+. The software tool we are using is called FLOT and is running under the open MIT license.

Official supported are: Internet Explorer 9+, Firefox 2.x+, Safari 3.0+, Opera 9.5+ or Konqueror 4.x+. We urgently recommend Firefox 14.x or higher. Also Opera is working well. Many other browsers doesn't work, especially with Windows7 64bit.

7.1.1 Firefox

Firefox is working since version 2.x+ Also with Windows7 64bit and Linux.

7.1.2 Opera

For Opera you have to set a certain switch: Please input at the adress line:

```
about:config
```

Then you get a menu with a lot of options.

Please slect the button:

```
UserPrefs
```

There will be a submenu opened:

```
Allow File XMLHttpRequest
```

please selct this option.

Save the settings and restart the Opera browser.

7.1.3 MS Internet Explorer

Internet Explorer 6.0 doesn't work. Internet Explorer 8.0 may work after some confirmed popup windows. Internet Explorer 9.x running with Window7 Professional 64bit doesn't work.

7.1.4 Google Chrome

Doesn't work with Windows7 64bit.

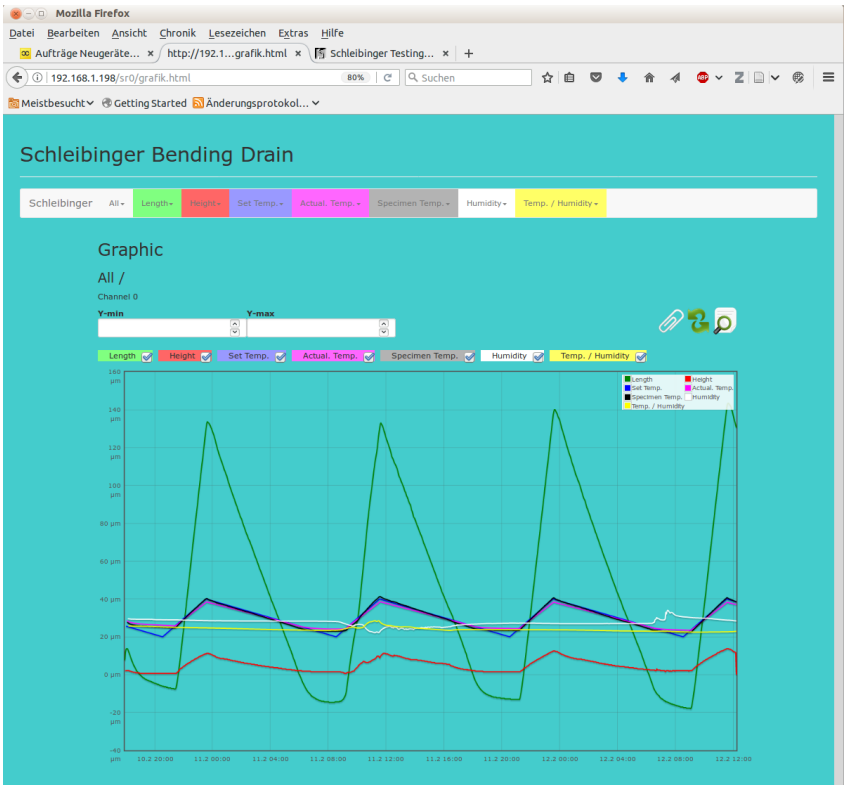

Figure 29: plotting a measurement curve in the Internet-Browser

7.2 User Interface

7.3 Channel Selection

In the upper area you may see check boxes where you may select the channels that should be shown. The color of the curves are the same then the background color of the channel names.

After selecting the required channels, you have to click on the icon with the two green arrows to reload and draw the data.

7.4 Zooming the Y-axis

The FLOT software is trying to find an optimal y-range for the data. You can select the range by putting in valid numbers in the min: and max: input fields.

7.5 Zooming the Time Axis

Please press the left mouse button and move the mouse over the region of interest in the time range. The background will change to light yellow. If you If release the mouse button again the plot will be refreshed. If you click on the magnifier icon the whole time range will be shown again.

7.6 Insert a Legend

Clicking on the paper-clip icon will open an input field for a text legend, shown in the graph.

7.7 Printing the Graph

Firefox: please use the print function of the browser. Select actual frame in the in the printing options dialog of the browser to print the graph without the menus around.

8 Bibliography

References

[1] EN 13892-9: “Methods of test for screed materials, Part 9: Determination of shrinkage and swelling” 03/2017.

[2] ASTM C 1581-09a. “Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage” , 2009

[3] ASTM C 827-95a (Reapproved 1997) “Standard Test Method for Change in Height at Early Ages of Cylindrical Specimens from Cementitious Mixtures”, 1997

[4] Bludau W, “Lichtwellenleiter in Sensorik und optischer Nachrichtentechnik”, Springer Berlin 1998

[5] Breitenbücher R, “Zwangsspannungen und Rissbildung infolge Hydratationswärme” Dissertation TU München, München, 1989

[6] Bühler E, Zurbriggen R, “Mechanisms of early shrinkage and expansion of fast setting flooring compounds” Tagung Bauchemie, 7./8. Oktober 2004 in Erlangen Neubauer J, Goetz-Neunhoeffer F, hrsg. von der GDCh-Fachgruppe Bauchemie, 2004

[7] EN 12617-4:2002, “Products and systems for the protection and repair of concrete structures. Test methods, Part 4: Determination of shrinkage and expansion”

[8] Gerstner B, Haltenberger H, Teubert O, Greim M, “Device for measuring deformation of mortar in two directions under different temperature conditions has sensors for simultaneous measurement of vertical and horizontal mortar movement” German Paten Application DE000010123663A1, 2001

[9] Greim M, Teubert O, “Appliance for detecting initial expansion and shrinkage behavior of building materials based on contactless measurement of change in filling level of container of fresh material specimens until set”, German Patent Application DE000010046284A1, 2000

[10] Ilschner B, Singer RF, "Werkstoffwissenschaften und Fertigungstechnik: Eigenschaften, Vorgänge, Technologien" Springer Berlin 2010

[11] Jensen OM, Hansen PF. “A Dilatometer for Measuring Autogeneous Deformation in Hardening Portland Cement Paste” Materials and Structures : Research and Testing. 28:406-409, 1995

[12] Lorenz OK, Schmidt M, “Aufschüsseln schwimmend verlegter Zementestriche”, ibausil, 13. Internationala Baustofftagung September 1997, hrsg. Stark J. Band 1, 1997

[13] Lura P, Durand F , Jensen OM, “Autogenous strain of cement pastes with superabsorbent polymers”, International RILEM Conference on Volume Changes of Hardening Concrete: Testing and Mitigation, Jensen OM, Lura P, Kovler K (eds), RILEM Publications SARL 2006

[14] Sören Eppers Assessing the autogenous shrinkage cracking propensity of con crete by means of the restrained ring test Die Bewertung der autogenen Schwindrissneigung von Beton mit Hilfe des Ring-Tests

[15] Sören Eppers, Christoph Müller On the examination of the autogenous shrinkage cracking propensity by means of the restrained ring test with particular consideration of temperature influences

[16] Prof. Dr.-Ing. Harald S. Müller, Dipl.-Geol. Dipl.-Min. Astrid Hirsch, Dr.-Ing. Vladislav Kvitsel Institut für Massivbau und Baustofftechnologie, Karlsruher Institut für Technologie (KIT) Prof. Dr.-Ing. Rolf Silbereisen, Dipl.-Ing. Carsten Becker CEMEX Deutschland AG Schwindarmer Beton ? Entwicklung und Möglichkeiten

[17] Frank Apicella, BASF Corp - Construction Chemicals "Crack-Free" Repair Materials ... Are We There Yet ? Minnesota Concrete Council

[18] Jae-Heum Moon,Farshad Rajabipour,Brad Pease,and Jason Weiss Quantifying the Influence of Specimen Geometry on the Results of the Restrained Ring Test Journal of ASTM International, Vol. 3, No. 8, Paper ID JAI100436

[19] Henkensiefken et al.2008 CBC Reducing Restrained Shrinkage Cracking in Concrete: Examining the Behavior of Self-Curing Concrete Made using Different Volumes of Saturated Lightweight Aggregate

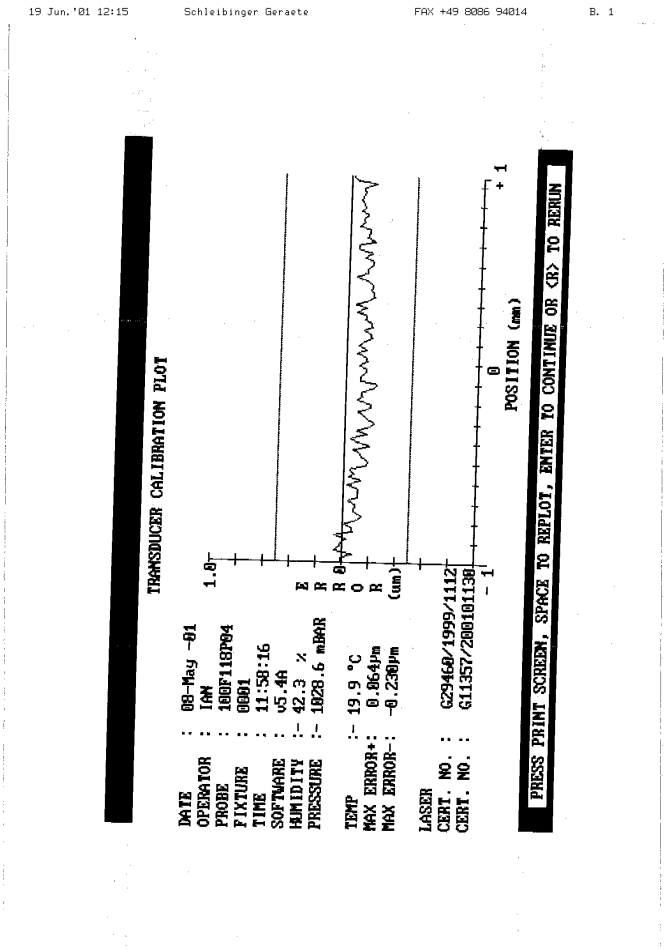

Figure 30: Calibration plot

9 Calibration Sheet Laser sensor

10 Calibration Sheet Temperature Sensors

10.1 Sensor 1

Temperature 2	
26.1	35.4
25.34	34.6
2534	3460
	C

10.2 Sensor 2

Temperature 2	
26.4	35.7
25.34	34.6
2534	3460
	C

List of Figures