Test Report No. 2012-039-A

Tensile Breaking Strength, Stress-Strain and CTE Tests on conductor ACSR Falcon

Customer: Midal Cables Ltd.
Manama, Kingdom of Bahrain

Test Objects: Conductor ACSR Falcon (806-A1/S1A-54/19)

Tests conducted: Tensile Breaking Strength acc. IEC 61089
Stress-Strain acc. IEC 61089
Coefficient of Thermal Elongation acc. SAG Test Method

Test Engineer: Dipl.-Ing. Unterfinger Jérémy

Test Sites: SAG Versuchs- und Technologiezentrum, Langen

Date of Tests: May 2012

DAkkS Deutsche Akkreditierungsstelle D-PL-17453-01-00

Testing Laboratory accredited by DAkkS against DIN EN ISO/IEC 17 025

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Pöhlmann

Unterfinger

This report consists of: 26 pages with 7 tables, 10 figures, 9 diagrams, - drawings and 1 annex

1. Summary

In May 2012, type tests were carried out on behalf of Midal Cables LTD, Manama, Kingdom of Bahrain, by Versuchs- und Technologiezentrum (Research and Technology Centre) of SAG GmbH, Langen, Germany.

The tests were performed on conductor type ACSR Falcon (806-A1/S1A-54/19). The conductor was manufactured by Midal Cables Ltd according to the datasheet in Figure 4. The sample was delivered on a drum (See Figure 1).

The following tests were performed:

- Tensile Test acc. IEC 61089
- Stress-Strain Test acc. IEC 61089
- Determination of thermal elongation coefficient (CTE) according to SAG – test method

Results:

Tensile Test :
The conductor broke at 268,2 kN above the RTS of 249,7 kN. The requirements are fulfilled.

Stress-Strain:

The following parameters for a fourth order polynomial stress strain relation (a0 to a4) and for the module of elasticity (E) were derived:

	a0	a1	a2	a3	a4	E
Aluminum	0	444,4	-486,9	17,6	206,5	490,5
Core	0	161,1	194,3	- 446,3	243,9	202,5

Stress*Ratio [MPa], strain [%]

Breaking load after stress strain test (informative):

- On the complete conductor : 267,9 kN (RTS : 249,7 kN).
- On the core : 150,9 kN (approx. 1473 MPa).

Coefficient of thermal elongation

Aluminum	$24{,}36*10^{-4}$
Core	$12{,}26*10^{-4}$

Temperature [°C], strain [%]

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2. Introduction

In May 2012, type tests were carried out on behalf of Midal Cables LTD, Manama, Kingdom of Bahrain, by Versuchs- und Technologiezentrum (Research and Technology Centre) of SAG GmbH, Langen, Germany.

The following tests were performed:

- Tensile Test acc. IEC 61089
- Stress-Strain Test acc. IEC 61089
- Determination of thermal elongation coefficient according to SAG – test method

The tests were witnessed by following representatives:

For Altalink : - Danielle Phaneuf

For SNC Lavalin : - Magdi F. Ishac

For SAG : - Jérémy Unterfinger

- Wolfgang Marthen

A minutes of meeting signed by the representatives is attached in Annex 1.

3. Test Objects

The test object was the conductor ACSR Falcon (806-A1/S1A-54/19). The conductor was manufactured by Midal Cables Ltd according to the datasheet in Figure 4. The sample was delivered on a drum (See Figure 1 and Figure 2). The end of the conductor was also marked with a white paper (see Figure 3).

Figure 1 : Drum of conductor ACSR Falcon

Figure 2 : Identification of the drum

Figure 3 : Mark of the conductor

ISO 9001
ISO 14001
OHSAS 18001
Certified by

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هاتف: ٨٣٢٨٣٢ ١٧ / ٨٣٢٨٣٣ ١٧ +٩٧٣
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Guaranteed Technical Parameters of Over Head ACSR Conductor

Item	Description	Unit	Guaranteed Technical Particulars
1	Code Name		806-A1/S1A-54/19 (ACSR Falcon)
2	Manufacturer		Midal Cables Ltd
3	Country and place of manufacturing		Bahrain
4	Applicable Standards		CAN/CSA-C61089-11
5	Type of conductor		ACSR
6	Number and Diameter of wires		
	Aluminium	N°/mm	54 / 4.36
	Steel	N°/mm	19 / 2.62
7	Outer diameter of stranded conductor	mm	39.3
8	Total Area of conductor		
	Aluminium	mm^2	805.8
	Steel	mm^2	102.43
	Total	mm^2	908.2
9	Mass of conductor	kg/km	3034
10	Conductor Strength	kN	249.7
11	Maximum DC Resistance of conductor at 20°C	Ω/km	0.03589
12	AC Resistance 25°C 75°C 125°C	Ω/km	 0.03795 0.04501 0.06275
13	Max continuous current rating (assuming 25°C ambient& wind@0.61 m/s)	A	1416@75°C 1963@125°C
14 a. b. c. d.	Type of steel Tensile strength - minimum Stress at 1% extension - minimum Minimum elongation to break in 250mm GL	 MPa MPa %	Class A Galvanized Type - S1A 1310 1140 3.5
15 a. b. c. d.	Type of Aluminum Tensile strength - minimum Minimum Elongation to break in 250mm GL Conductivity at 20°C	 MPa % % IACS	1350-H19 Type A1 165 1.9 61

GTP Ref No.2011G11 Rev#2 dtd.04022012

Figure 4 : Datasheet of the conductor ACSR Falcon – data given by Midal Cable

4. Tests Descriptions

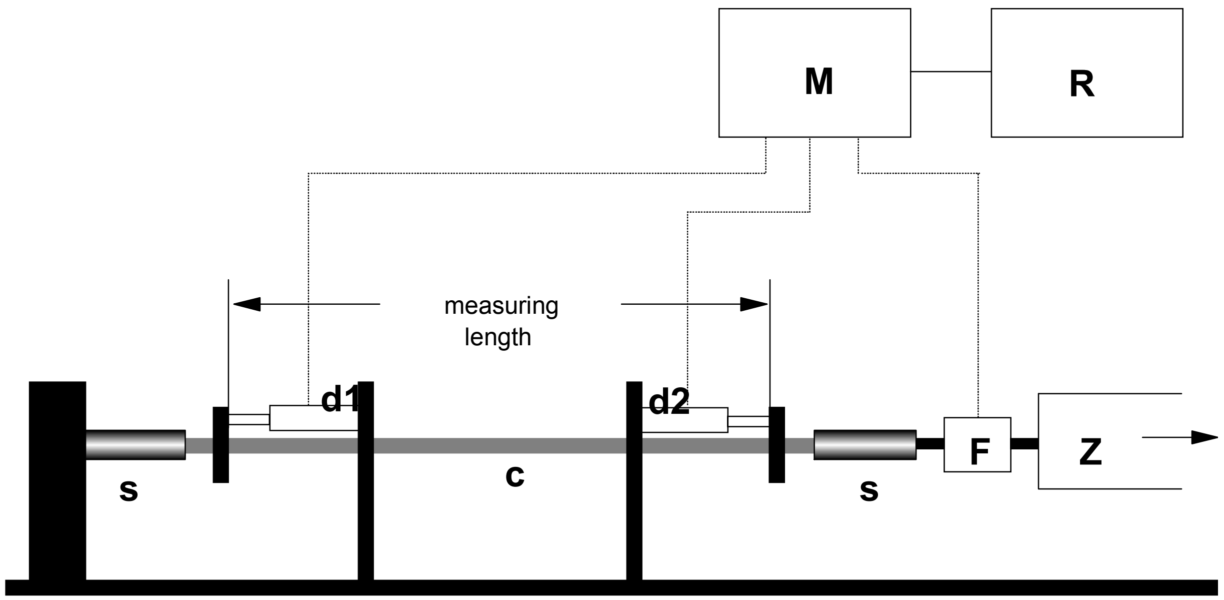
4.1. UTS and Stress-Strain

Both tests are performed according to IEC 61089 or EN 50182 in a horizontal 600 kN class1 tensile testing machine. The sample will be kept at the end in special resin clamps, in order to avoid pressure and deformation of the aluminum wires. The free sample length will be larger than 400xD. The load rate is corresponding to the relevant standard.

Measured signals are recorded continuously by a PC.

For the UTS the load is increased at a steady rate until breakage of at least one wire. On ACSR conductors the test is then continue until breakage of the steel core for information purpose.

For stress strain test two measuring flanges are mounted on the specimen close to the clamps at a load of 2 kN, thus marking the initial length, which will be recorded. The movement of the flanges is monitored during the test by displacement transducers. These signals together with the measured initial length are used for calculation of strain.



c	conductor	F	force transducer
d1, d2	displacement transducer	Z	tensile testing machine
s	resin anchor clamp	M	multi channel amplifier
		R	computer

Figure 5 : Arrangement for stress-strain test

Load will be increased to 30% RTS and maintained for 30 min, then it will be released. The next steps are 50, 70 and 85% of RTS whereas the holding periods are 1 h each. After the final unloading the load is increased again for breakage after removal of the length transducers.

For conductors with different core material a test on a second sample is performed afterwards. The outer layers are removed from the sample, so only the core is loaded in the test. Elongation is measured in the same manner than for the complete conductor. Load steps then are defined according to the strains measured on the complete conductor at the beginning of the holding periods while the load then is maintained at the same level for 0.5 h or resp. 1 h.

The result of the test is a curve stress vs. strain and a polynomial through the points at the end of the holding periods. From the releasing curves the modulus of elasticity at the load steps can be calculated.

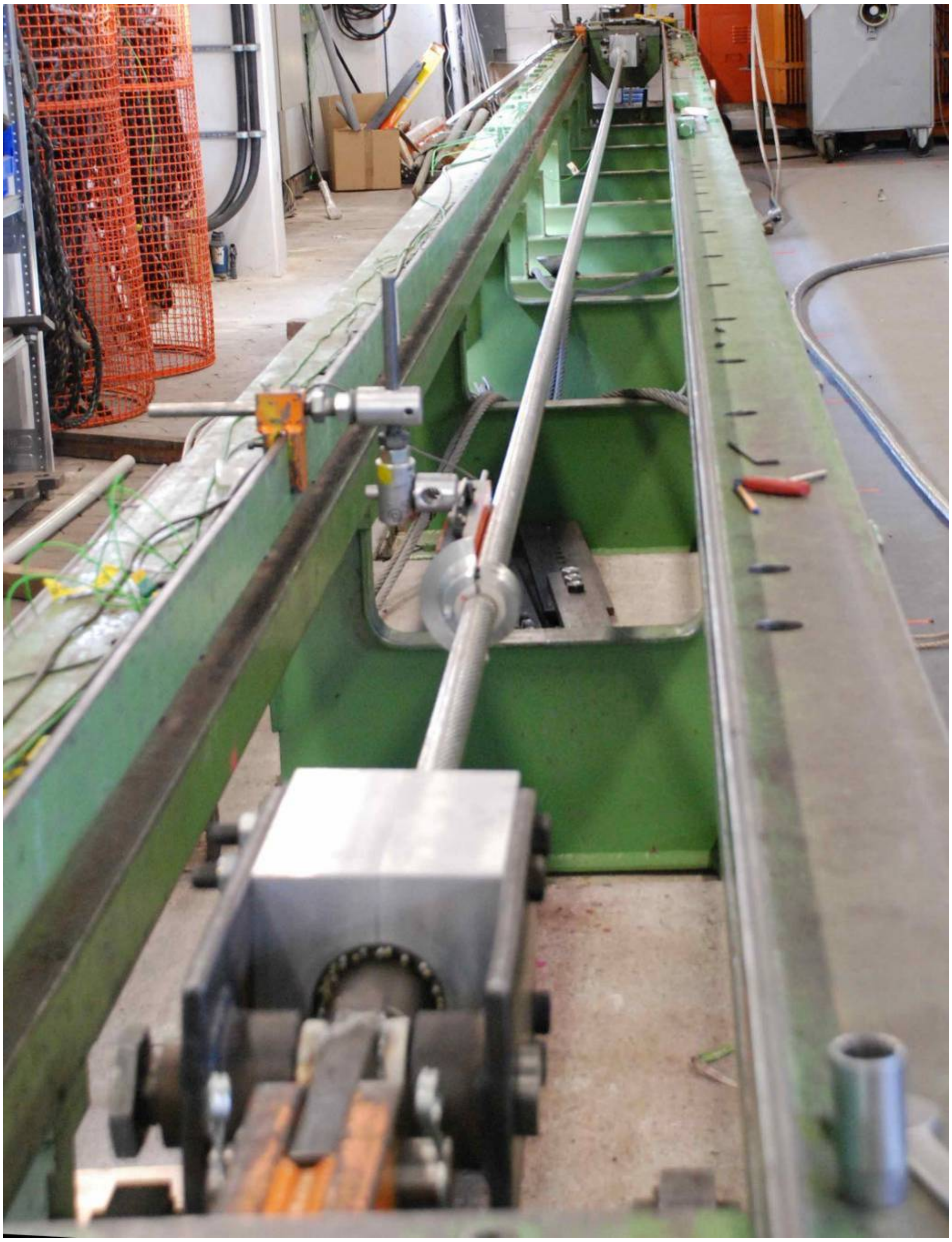


Figure 6 : ACSR Falcon in the tensile machine for the stress-strain test

4.2. Coefficient of Thermal Elongation

Tests are performed in a horizontal 600 kN class1 tensile testing machine. The set-up is similar to that of a stress-strain test according to IEC 61089 or EN 50182. The sample will be kept at the ends with come along clamps. The sample length will be larger than 400xD.

The termination clamps are fixed to the tensile testing machine by insulators. Close to the termination clamps a transformer is connected by parallel grove clamps.

Temperature of the conductor is measured by 5 equidistant thermocouples which are put underneath the wires of the outer layer.

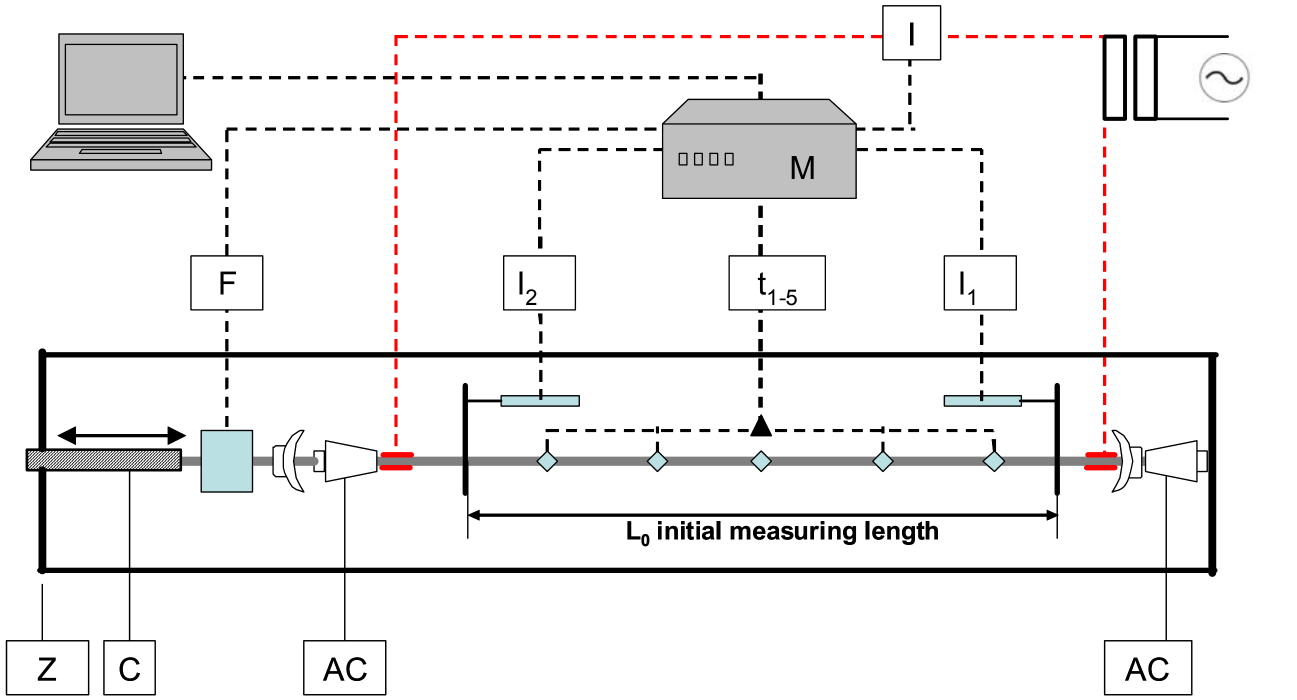
For the test two measuring flanges are mounted on the specimen about 1 m from the parallel grove clamps at a load of 2 kN, thus marking the initial length L_0. The movements of the flanges are monitored during the test by length transducers. These signals together with the measured initial length are used for calculation of thermal elongation.

Measured signals are recorded continuously by a PC at a rate of appr.1 sample /s.

Load will be increased to 20% RTS and maintained at this value throughout the test.

Current is set to the max. allowed value and temperature is raised to the specified value under constant tensile load. After reaching the temperature, current is controlled to keep the temperature for around 30 min to allow the system to stabilize thermally. Then current is switched of and the conductor is allowed to cool down under constant tension up to around 35 °C.

The result of the test is a curve temperature vs. strain, the slope is corresponding to the coefficient of elongation.



Z	tensile Testing Machine	F [kN]	load measurement
AC	resin anchor clamp	t [°C]	temperature measurement
M	multi channel amplifier	$l_{1,2}$ [mm]	strain measurements
Z	tensile testing machine	I [A]	current measurement

Figure 7: Set up for measurement of thermal elongation

Figure 8 : ACSR Falcon in the tensile machine for the CTE Test

4.3. Equipment

Table 1 : Measurement equipment

Equipment	Magnitude measured/ Place	Manufacturer	Type	Serial number	Calibration date
Tensile machine 120 / 600kN	Mechanical load and displacement	Mohr und Federhaff AG		9/71/2510-0	23/04/2011 (for 2 years)
Displacement transducer	Displacement Right	TML	SDP-200D	BAJ 09116	08/05/2012
Displacement transducer	Displacement Left	TML	SDP-300D	BAK 09316	08/05/2012
Thermocouple	Temperature Left	Thermocoax	K	Te_d10_L2_003-L10_003	14/02/2012
Thermocouple	Temperature Left-Center	Thermocoax	K	Te_d10_L2_049-L10_049	21/03/2012
Thermocouple	Temperature Center	Thermocoax	K	te_d10_L2_059-L5_059	23/03/2012
Thermocouple	Temperature Center-Right	Thermocoax	K	te_D10_L9_014-L9_014	12/03/2012
Thermocouple	Temperature Right	Thermocoax	K	te_d10_L2_031-L19_032	14/03/2012
Thermocouple	Temperature Ambient	Thermocoax	K	te_d10_L2_005	14/02/2012

5. Tests Results

5.1. UTS

The exact length of the sample was 16,33 m. The sample was loaded until breakage occurred. Diagram 1 indicates the loading curve until breakage of the specimen.

The aluminum wires broke at 268,2 kN above the RTS (249,7 kN). The tensile test was continue until the core broke at 152,0 kN. Figure 9 shows the breakage area of the aluminum layers.

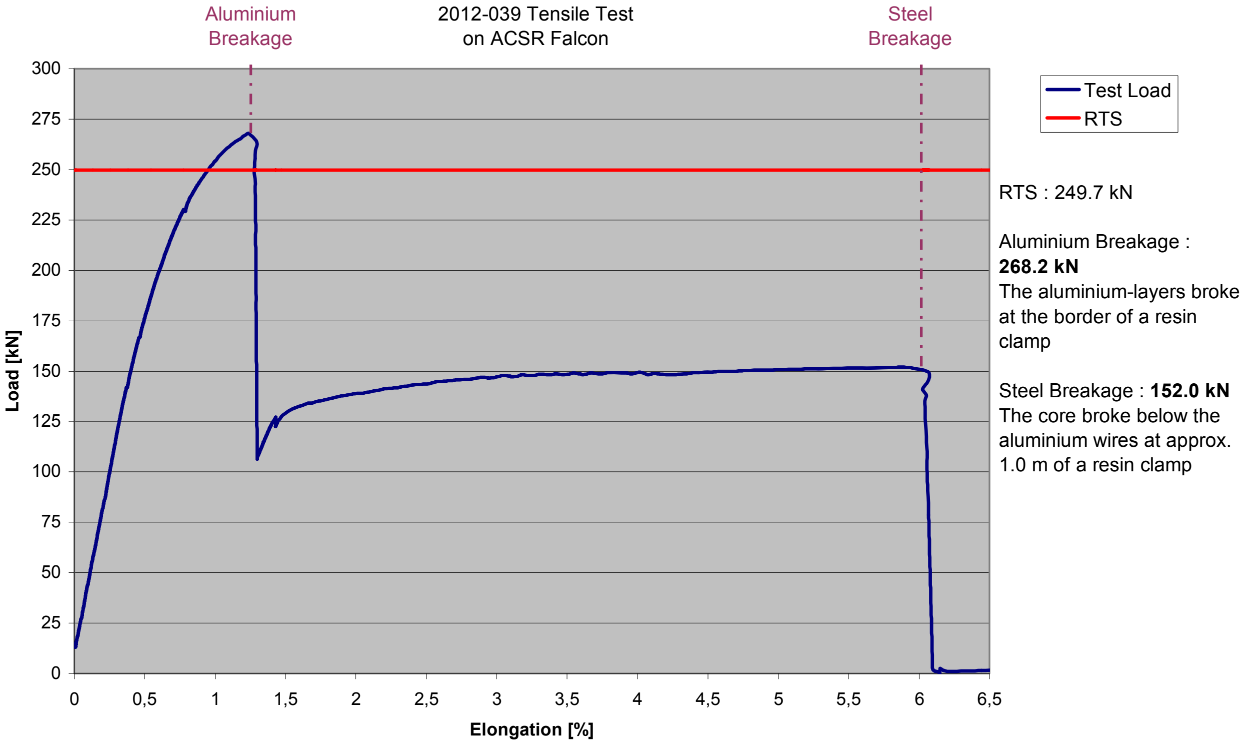


Diagram 1 : Tensile test on ACSR Falcon

The requirements are fulfilled.

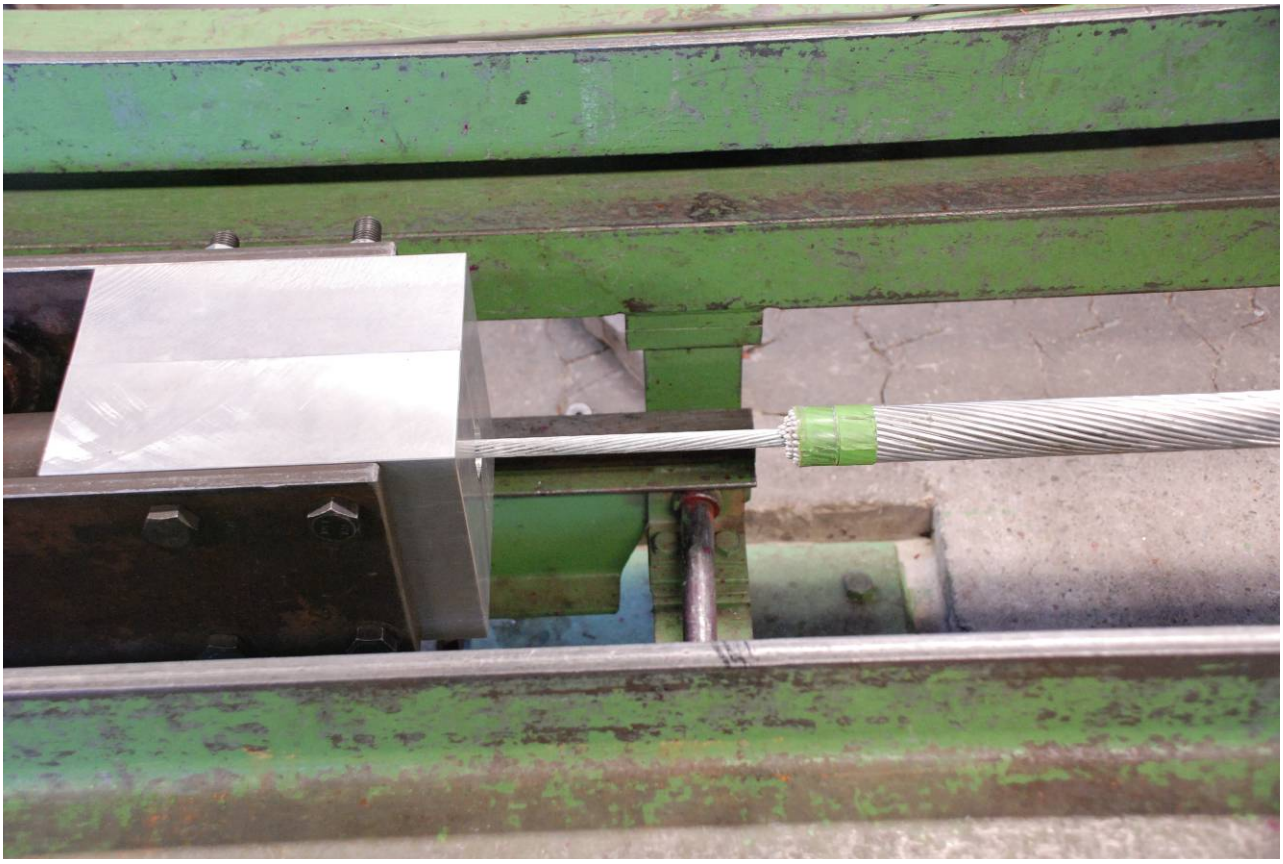


Figure 9 : Breakage of the aluminum at the border of the clamp during the tensile test

5.2. Stress-Strain

5.2.1. Test Parameters

The cross sectional areas needed for the computation of the different moduli were extracted from the datasheet of the conductor. The values are listed in Table 2.

Table 2 : Cross sectional areas of the conductors

	Cross sectional area [mm²]		
	Core	**Aluminum**	**Conductor**
ACSR Falcon	102,43	805,8	908,2

Before the beginning of the test, the sample lengths (between the resin clamps, see Figure 5) and the measuring lengths (between the fixed flanges of measurement, see Figure 5) were measured and listed. The values are given in the Table 3.

Table 3 : Measuring length and sample length of the stress-strain test

	measuring length [m]	sample length [m]
ACSR Falcon : complete conductor	14,31	16,31
ACSR Falcon : core	14,36	16,36

The temperatures during the stress-strain tests are listed in the Table 4:

Table 4 : Temperature during the stress-strain tests

		Temperature [°C]	
		Complete conductor	Core
ACSR Falcon	Min	18,6	21,8
	Max	21,9	24,0
	Average	20,6	22,9
	st. deviation	0,86	1,60

5.2.2. Final modulus of elasticity

From the curves on Diagram 2 and Diagram 3, the strain until reaching each load step and the creep on the conductor during the holding periods of 0,5 hour respectively one hour can be seen.

From the releasing curves after the load steps of 50%, 70% and 85% RTS the following final modulus of elasticity were evaluated for the complete conductor and for the core.

Table 5 : Final moduli of elasticity

Releasing curve after load step	Final modulus of elasticity [kN/mm²]		
	Core (measured)	Conductor (measured)	Aluminum (calculated)
50% RTS	180,3	68,5	54,3
70% RTS	181,3	70,2	56,1
85% RTS	179,6	69,3	55,3

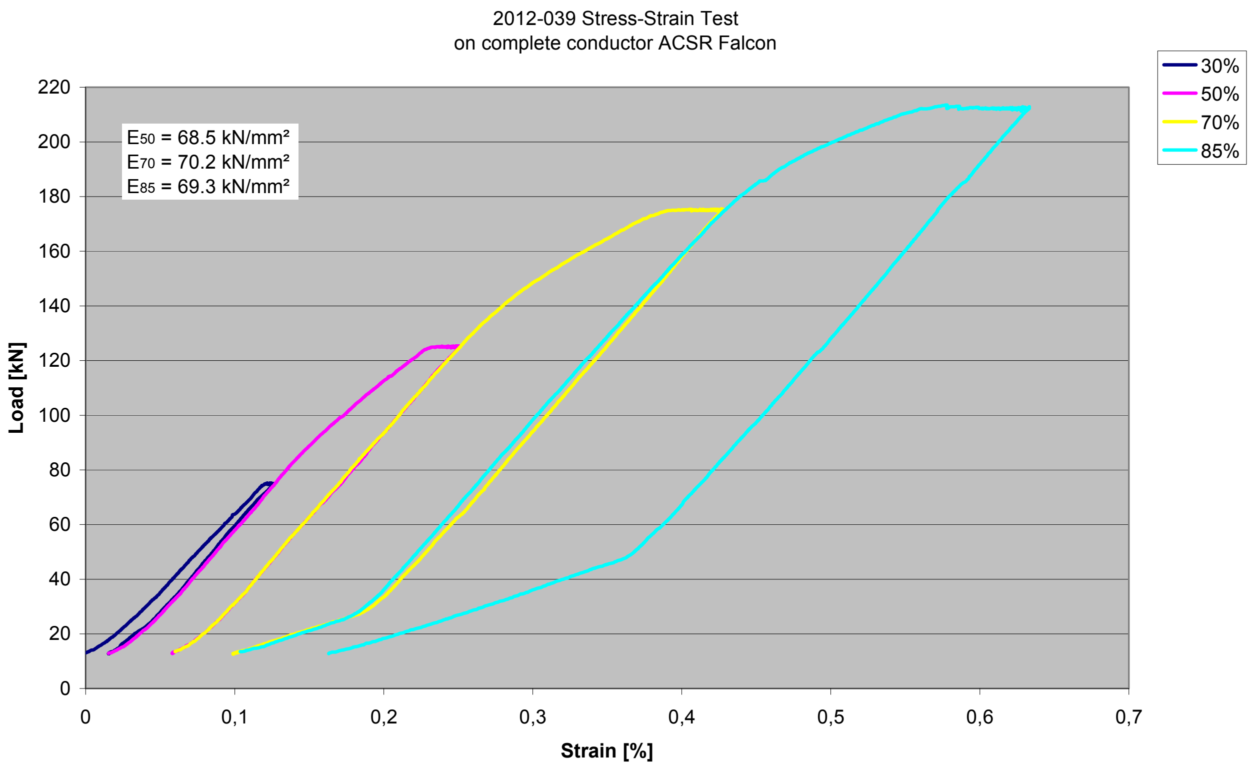


Diagram 2 : Measured data during the stress-strain test on ACSR Falcon

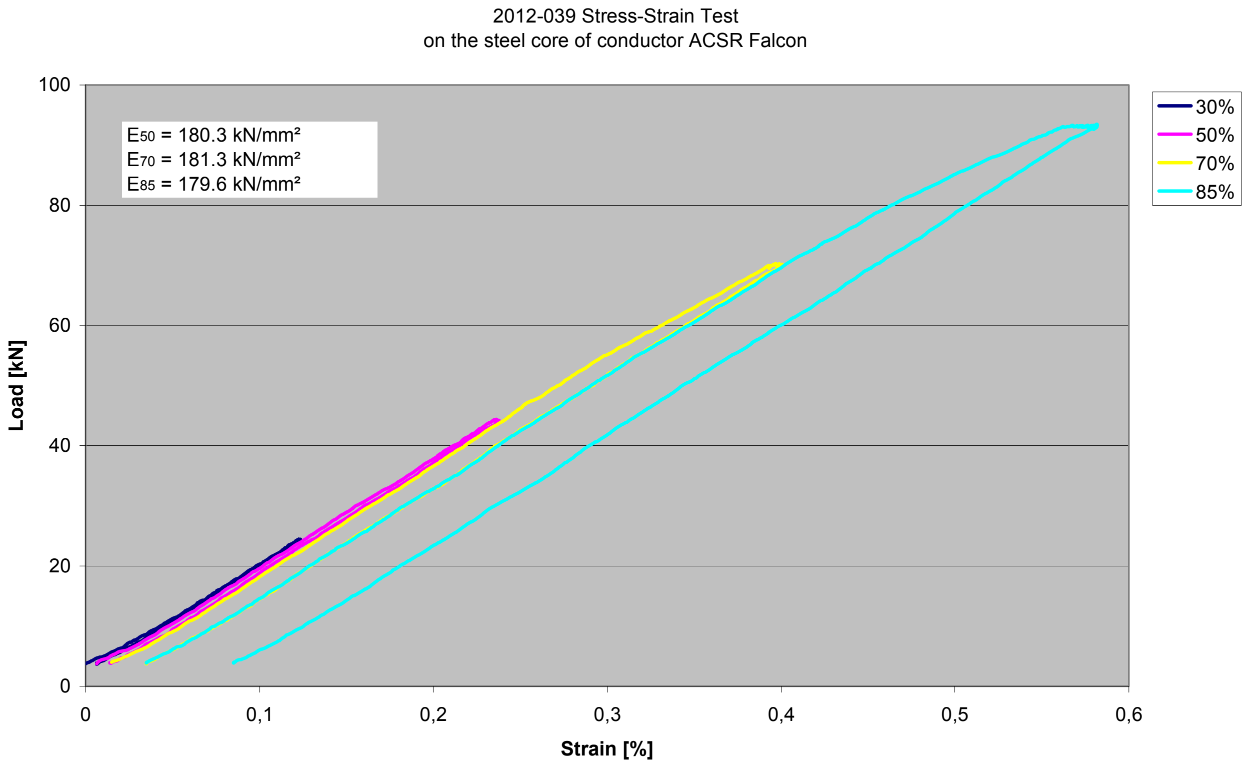


Diagram 3 : Measured data during the stress-strain test on the core of ACSR Falcon

5.3. Determination of Parameters for PLS-CADD

For the software PLS CADD, the moduli of elasticity must be computed with the following equation :

$$\frac{S_x}{S_{conductor}} \cdot \sigma_x = E_x \cdot \varepsilon$$

With: ε : strain [%],

σ_x : stress of the aluminum or the core [MPa],

S_x : conductor's, core's or aluminum's cross sectional area [mm²],

E_x : Module of elasticity of the conductor or the core [MPa]

For the step at 85% RTS, the following moduli of elasticity were computed:

Final modulus of elasticity [MPa]		
Core	Conductor	Aluminum
202,5	693,0	490,5

5.3.1. Initial stress-strain curve

The initial stress-strain curves were determined by 4 degrees polynomials according to IEC 61089 section B.8. They are listed in the Table 6.

The initial stress-strain curve of the core has been determined with a linear curve using the final module of elasticity at 85% (see Table 5).

Table 6 : Initial stress-strain polygons

Conductor	$\sigma_{Conductor}(\varepsilon) = 605{,}5 \cdot \varepsilon - 292{,}7 \cdot \varepsilon^2 - 428{,}7 \cdot \varepsilon^3 + 450{,}3 \cdot \varepsilon^4$
Core	$\sigma_{Core}(\varepsilon) = 1428{,}2 \cdot \varepsilon + 1722{,}4 \cdot \varepsilon^2 - 3956{,}7 \cdot \varepsilon^3 + 2162{,}3 \cdot \varepsilon^4$
Aluminum	$\sigma_{Aluminium}(\varepsilon) = 500{,}9 \cdot \varepsilon - 548{,}8 \cdot \varepsilon^2 + 19{,}8 \cdot \varepsilon^3 + 232{,}7 \cdot \varepsilon^4$

With: ε : strain [%],

σ : stress [MPa].

The stress is defined with the following formula:

$$\sigma_X = \frac{F}{S_X},$$

With: F: the mechanical load read from force transducer [N],

S_x : conductor's, core's or aluminum's cross sectional area [mm²] (Table 2).

The initial stress-strain polygon of the aluminum has been calculated with the following formula:

$$\sigma_{Aluminium} = \frac{\sigma_{conductor} \cdot S_{conductor} - \sigma_{core} \cdot S_{core}}{S_{aluminium}},$$

The Diagram 4 is illustrating the different initial stress-strain curves.

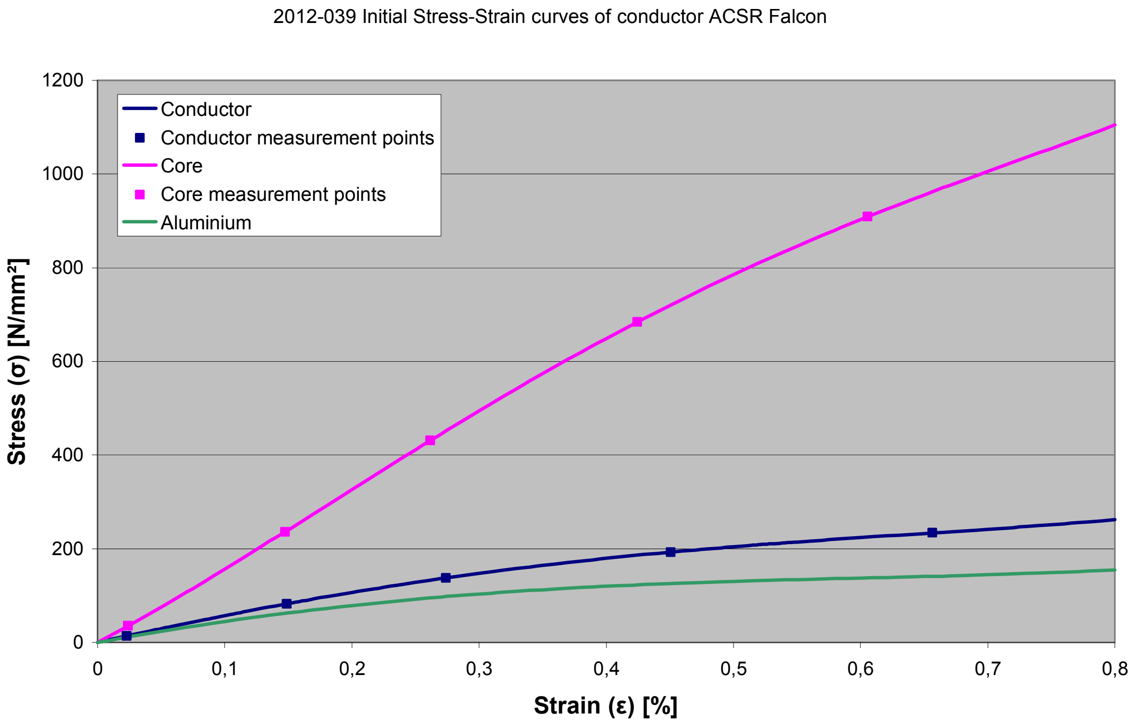


Diagram 4 : Initial stress-strain curves of ACSR Falcon

For the software PLS CADD, the polynomial coefficients of the initial stress-strain curves must be computed with the following equation :

$$\frac{S_x}{S_{conductor}} \cdot \sigma_x = A_0 + A_1 \cdot \varepsilon + A_2 \cdot \varepsilon^2 + A_3 \cdot \varepsilon^3 + A_4 \cdot \varepsilon^4$$

With: ε : strain [%],

σ_x : stress of the aluminum, the core or the complete conductor [MPa],

S_x : conductor's, core's or aluminum's cross sectional area [mm²],

A_x : the coefficients of 4th order of the initial stress-strain curves [MPa]

The following coefficients were computed:

	A_0	A_1	A_2	A_3	A_4
Conductor	0	605,5	- 292,7	-428,7	450,3
Core	0	161,1	194,3	- 446,3	243,9
Aluminum	0	444,4	-486,9	17,6	206,5

5.3.2. Tensile Test

At the end of the stress-strain test, the specimens were loaded until breakage occurred. Diagram 5 and Diagram 6 indicate the loading curves until the breakage of the specimen. The breaking loads are listed in the Table 7.

During the tensile test on the complete conductor, the aluminum wires broke 20 cm from a resin clamp at 267,9 kN above the RTS (249,7 kN). The load was then increased up to complete breakage of the conductor at 153,0 kN. The core broke at 50 cm of the same resin clamp. Figure 10 shows the breakage area of the aluminum layers.

During the tensile test on the core, the steel wires of the outer layer broke first at 150,9 kN approximately 1 m from a resin clamp. The other wires broke rapidly after. Figure 10 shows the breakage area of the steel wires.

Table 7 : Results of the tensile tests after the stress-strain tests

		RTS [kN]	Breakage of the aluminum [kN]	Breakage of the core [kN]	Breaking spot
ACSR Falcon	Complete conductor	249,7	**267,9**	**153,0**	Breakage of the aluminum wires first approx. 20 cm from a resin clamp
	Core	n.s.		**150,9**	The core broke 1 m outside of the resin clamp

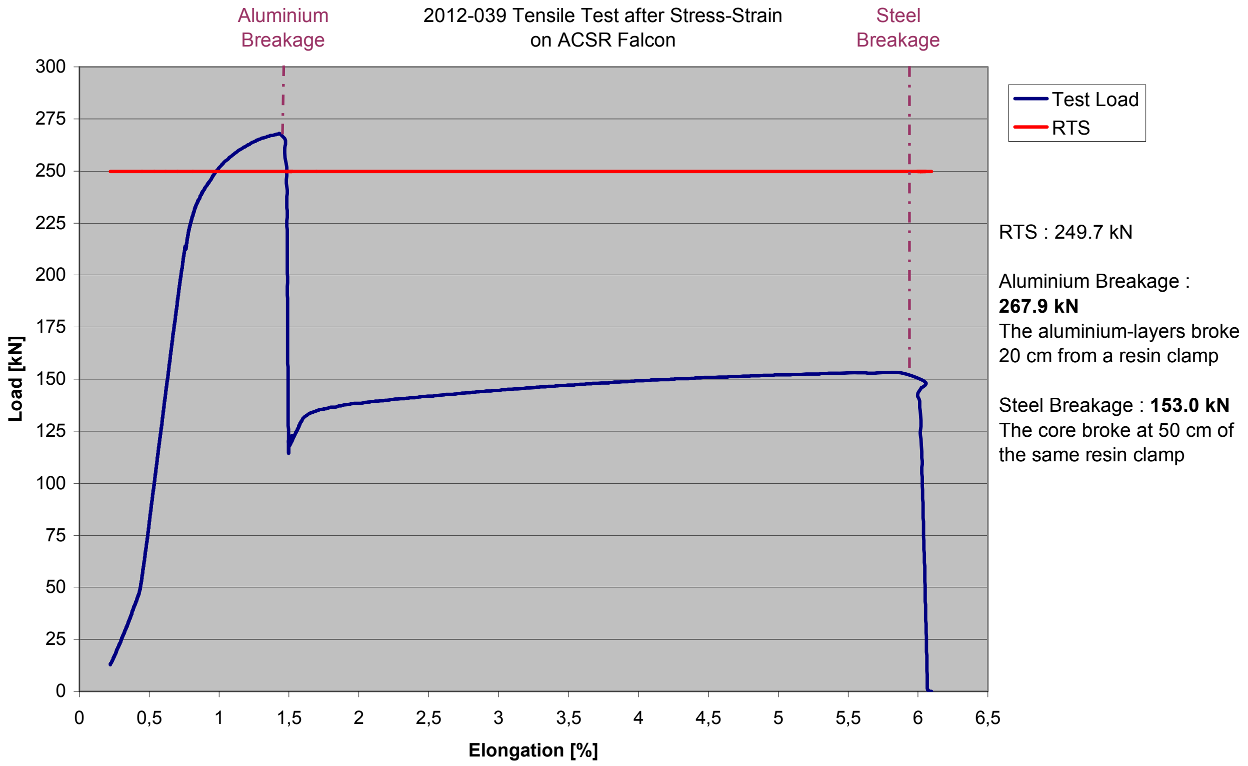


Diagram 5 : Tensile test after Stress-Strain on the complete ACSR Falcon

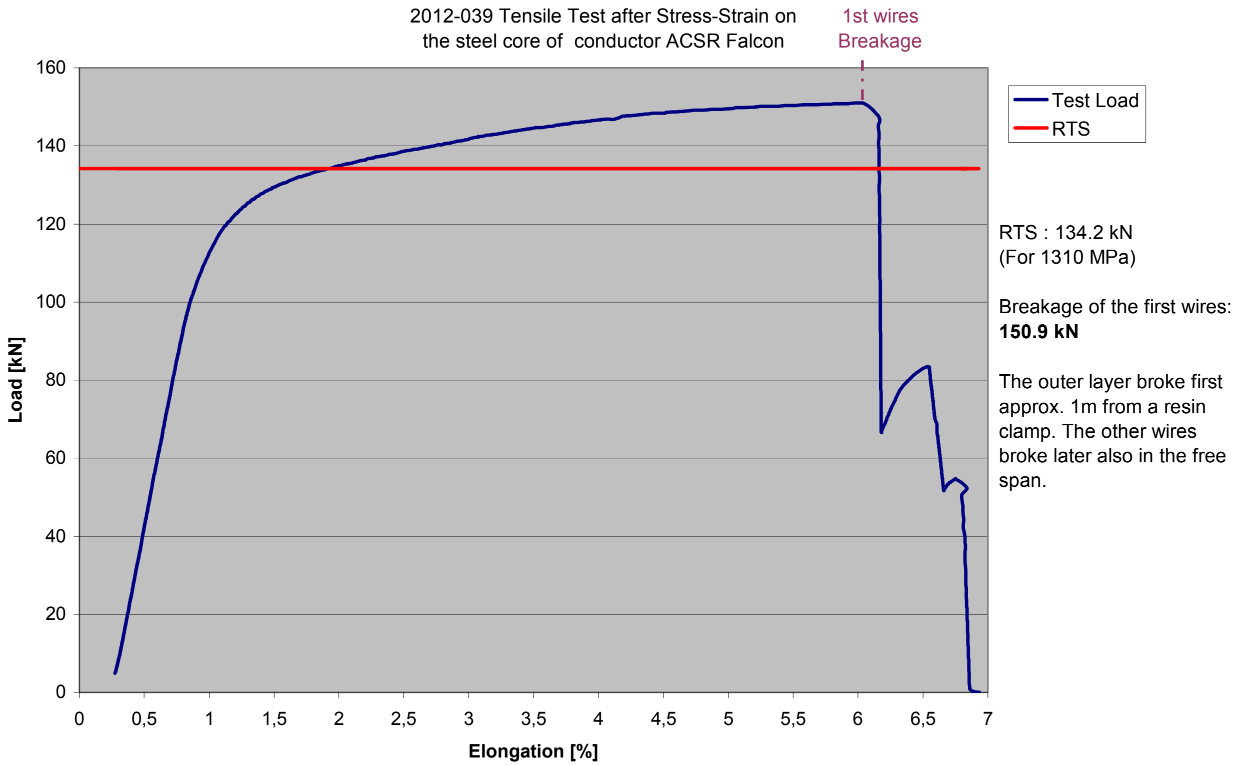


Diagram 6 : Tensile test after Stress-Strain on the core of the ACSR Falcon

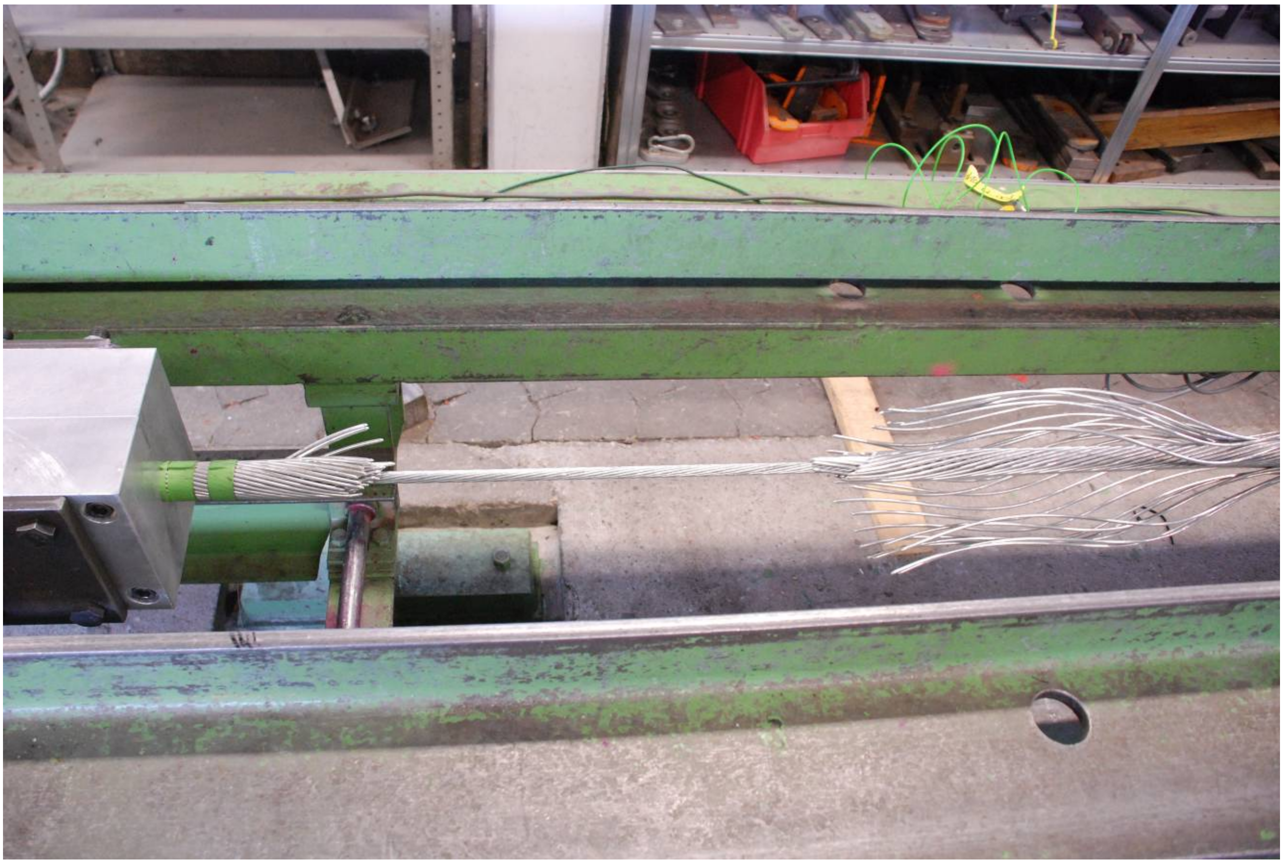


Figure 10 : Breakage of the aluminum after the tensile test on the complete conductor

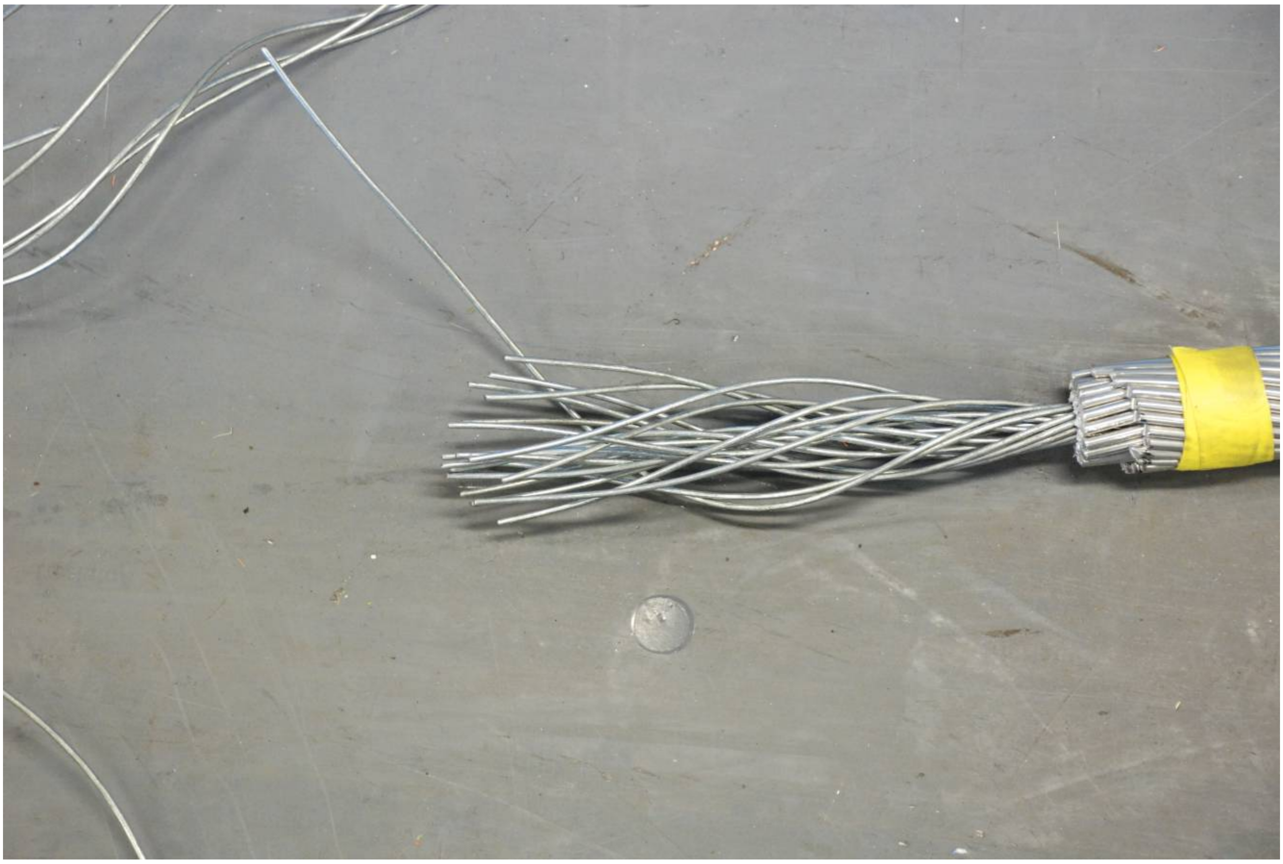


Figure 11 : Breakage after the tensile test on the core

5.4. Coefficient of Thermal Elongation

5.4.1. CTE of the complete conductor

The conductor tension was raised to 20 % RTS (49,9 kN) and maintained at this value throughout the test. Then the conductor temperature was increased slowly with current heating by a controllable transformer to a conductor temperature of 100°C, kept there for 30 min. and back to ambient with natural cooling by convection in resting air.

This sequence was performed two times on the same sample. The CTE were calculated for the heating and the cooling curves of the both sequences.

As final result, the coefficient of thermal elongation was determined from the second cooling curve:

$$\mathbf{21{,}19 * 10^{-6}\ 1/K}$$

Diagram 7 and Diagram 8 show the graphic representations of the temperature coefficient measurements on the complete conductor

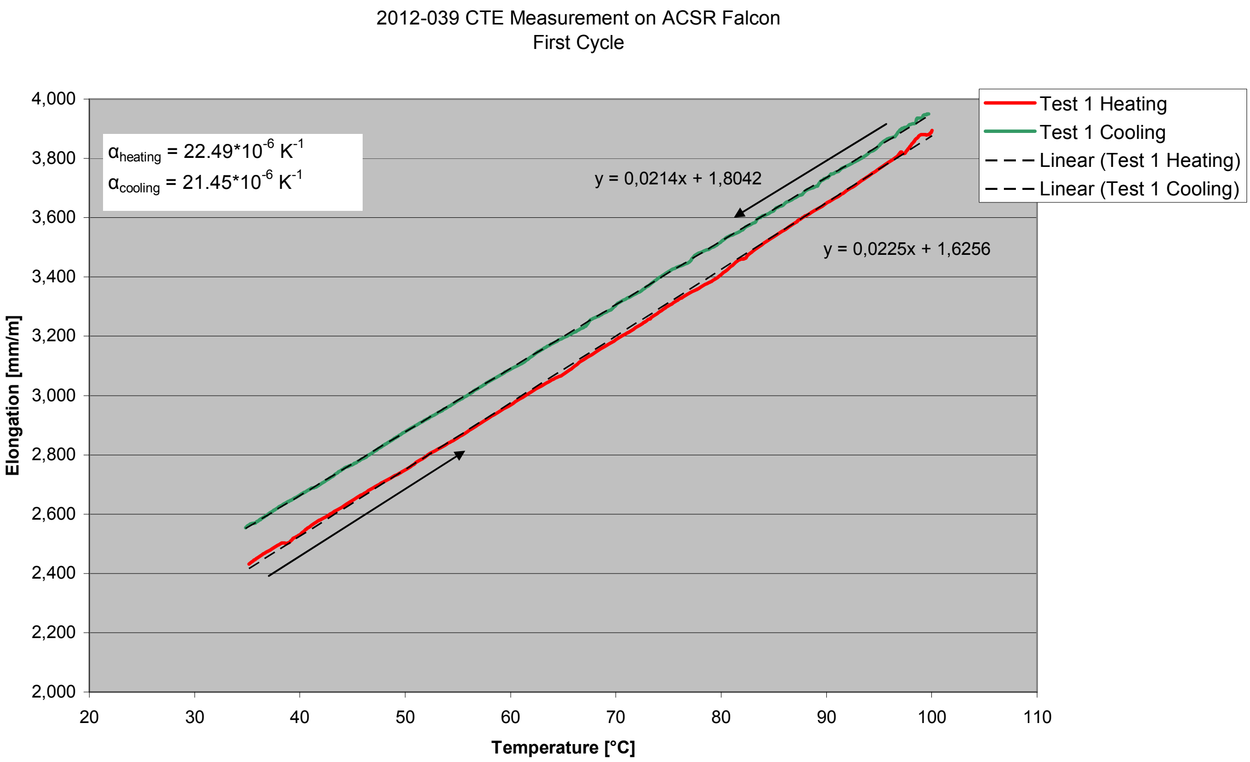


Diagram 7 : CTE Measurement - Heating and cooling curves of the first sequence on the complete conductor

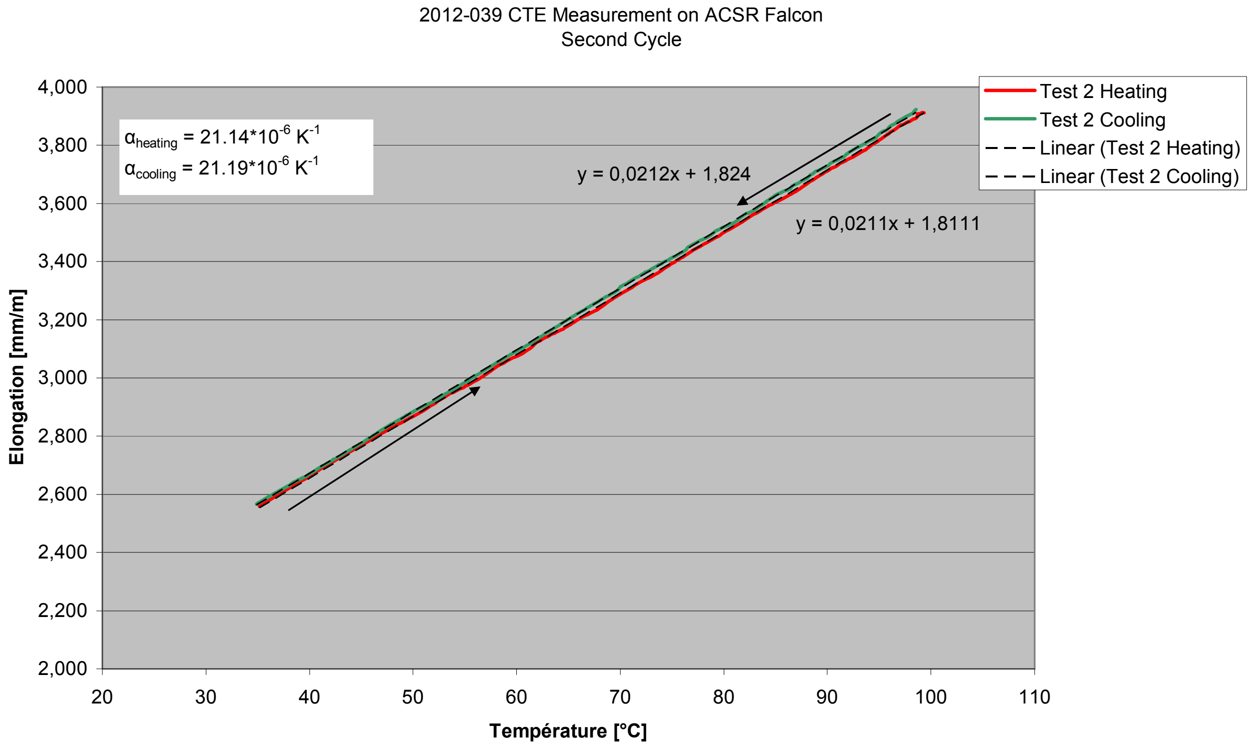


Diagram 8 : CTE Measurement - Heating and cooling curves of the second sequence on the complete conductor

5.4.2. CTE of the core

After the second sequence on the complete conductor, the aluminum layer were removed from the sample and the test was performed a third time only on the core.

The tension was raised to the theoretical tensile strength of the core for a tensile strength of 20 % RTS (49,9 kN) of the complete conductor. This value was computed using the following linear elastic model :

$$\sigma_{core} = \frac{\sigma_{conductor} \cdot E_{core}}{E_{conductor}}$$

With: σ_x : the stress on the core or the conductor [MPa],

E_x : Module of elasticity of the conductor or the core [kN/mm²]

As the stress-strain test was not performed before the CTE test on the core, a module of elasticity of 178 kN/mm² was used for this computation. This coefficient was computed from a small part of the curve of the stress-strain on the complete conductor at 85% RTS.

The computed load of 14,5 kN was maintained at this value throughout the test. Then the conductor temperature was increased to a temperature of 100°C, kept there for 30 min. and back to ambient with natural cooling by convection in resting air.

The coefficient of thermal elongation was determined from the cooling curve:

$$\mathbf{12{,}26 * 10^{-6}\ 1/K}$$

Diagram 9 shows the graphic representation of the temperature coefficient measurements on the core.

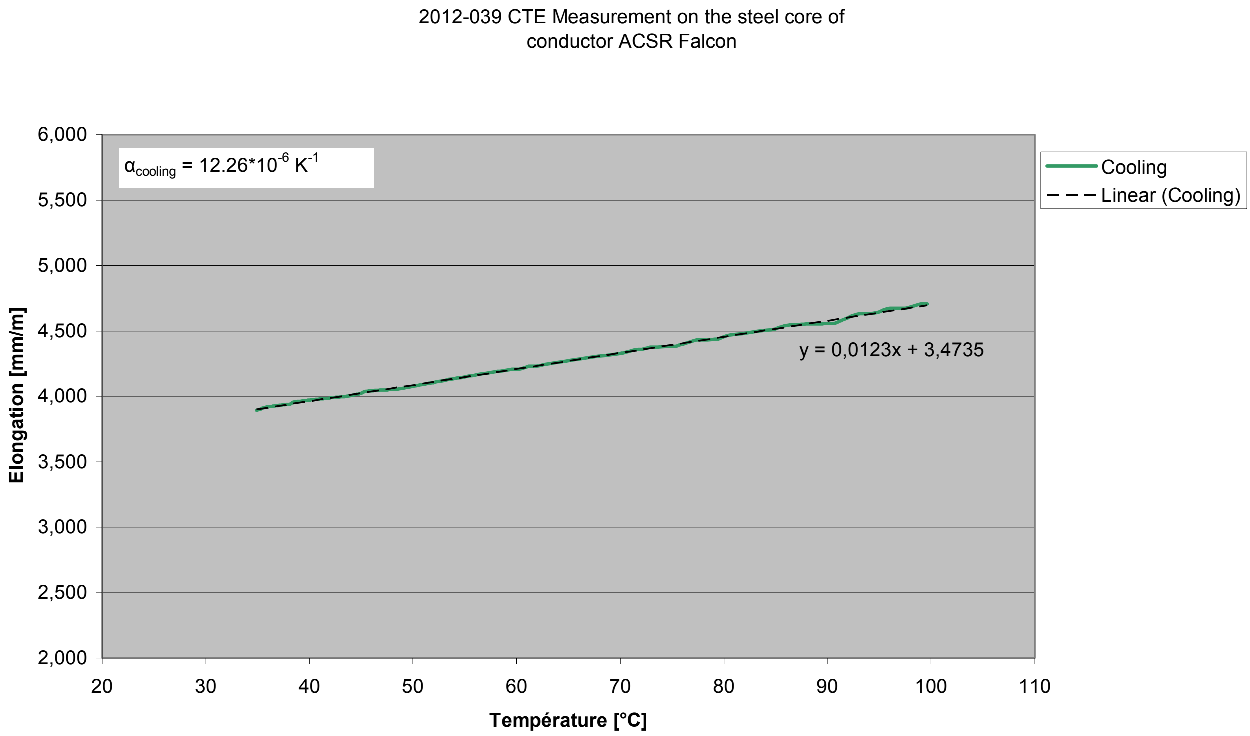


Diagram 9 : CTE Measurement _ Cooling curve of the core

5.4.3. CTE of the aluminum

Using the results of the CTE on the complete conductor and on the core, the CTE of the aluminum part can be computed using the following equation :

$$\varepsilon_{aluminum} = \frac{\varepsilon_{conductor}\left(m_1 \cdot E_{aluminum} + E_{core}\right) - \varepsilon_{core} \cdot E_{core}}{E_{aluminum} \cdot m_1}$$

With: ε_x : CTE of the core, the aluminum or the conductor [1/K],

E_x : Module of elasticity of the core, the aluminum or the conductor [MPa]

m_1 : The cross-sectional ratio of aluminum to steel (7,867)

The coefficient of thermal elongation of the aluminum is the following one:

24,36 * 10^{-6} 1/K

5.4.4. CTE Input Data for PLS CADD

For the software PLS CADD, the CTE must be computed with elongation expressed in percentage of the total length of the sample:

The following CTE were computed:

CTE [%/K]		
Core	Conductor	Aluminum
12,26*10^{-4}	21,19*10^{-4}	24,36*10^{-4}

6. Summary of the coefficients for PLS CADD

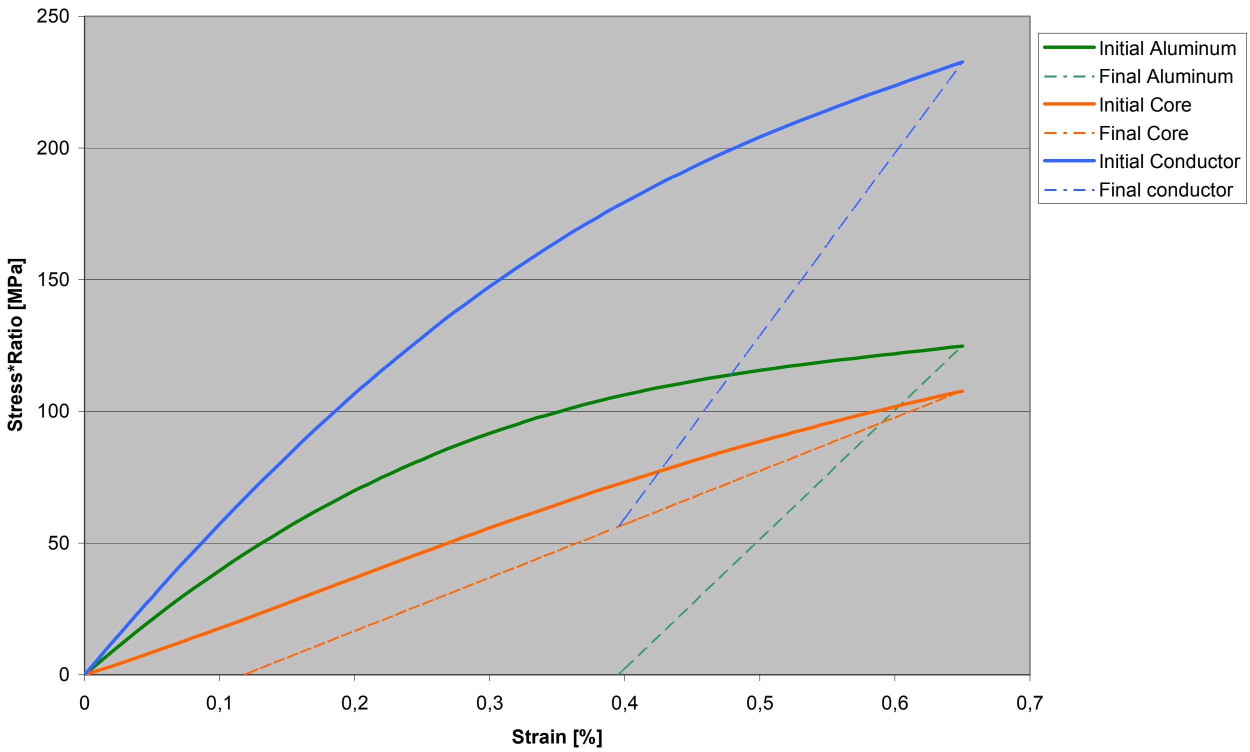


Figure 12 : Initial and Final stress-strain curves

Initial stress-strain curves after 1h:

		a0	a1	a2	a3	a4
Aluminum	Initial after 1h	0	444,4	-486,9	17,6	206,5
	Final after 10 years					
		b0	b1	b2	b3	b4
Core	Initial after 1h	0	161,1	194,3	- 446,3	243,9
	Final after 10 years					

Stress*area ratio [MPa], strain [%]

The final coefficients after 10 years will be added after the creep tests on the conductor and on the core.

Module of elasticity:

	E-Module [MPa]
Aluminum	490,5
Core	202,5

Stress*area ratio [MPa], strain [%]

Coefficient of thermal elongation

	CTE
Aluminum	$24,36*10^{-4}$
Core	$12,26*10^{-4}$

Temperature [°C], strain [%]

Annex

Annex 1

of the test report

2012-039 A

Minutes of Meeting

Contains 2 pages

	Minutes of Meeting Project 2012-034-Type Tests on ACSR Falcon Client: Midal Cables, Kingdom of Bahrain	SAG

Attendants:

Name	**Company**
Danielle Phaneuf	ALTALINK
Magdi F. Ishac	SNC Lavalin T&D
Wolfgang Marthen	SAG VTZ
Jeremy Unterfinger	SAG VTZ

Date of tests: 8th May – 10th May 2012

Date	Test Performed	Description / Remark	Result
08.05.2012	UTS	Achieved Breaking Load: 268.2, (core broke at 152 kN	o.k.
	Stress Strain Conductor	Modulus of elasticity 68.5 – 70.2 kN/mm² - Comment1 + Comment3	o.k.
09.05.2012	CTE of Conductor	2 cycles up to 100°C conductor temperature, coefficient from 2.nd cooling curve $21,19*10^{-6}$ 1/K - Comment2 + Comment3	o.k.
10.5.2012	CTE of core	One cycle up to 100°C, coefficient from cooling curve $12,26*10^{-6}$ 1/K - Comment2	o.k
10.05.2012	Stress Strain of core	Modulus of elasticity of the core 179,6 – 181,3 kN/mm² Modulus of elasticity of the aluminum 55,3 kN/mm² (calculated)	o.k

Comment 1: values are slightly higher (2%) than theoretical values, calculated by SAG10

Comment 2: Values are around 5% higher than theoretical value. This is in correspondence with the experience of the laboratory.

Comment 3: From the tests the parameters for PLS-CADD shall be derived. There different parameters for the conductor resp. the aluminium portion are to be given, which can only be derived from tests on complete conductor and on the core. Therefore it was agreed to perform following additional tests:

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- CTE of steel core
- Creep on steel core - one sample at load corresponding 35% RTS of complete conductor

CTE on the steel core was performed on 10th May with no additional charge.
The creep test on the steel sample will be started after availability of a place in the test bench in week 23.
A draft report with evaluation of 500 hrs will be submitted after end of the 1000 hrs tests on the complete conductor samples, the final report will submitted immediately after end of the test.

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