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Report 1538aE5327

Tensile tests for FLEXWELL- district heating cable

Order of

Brugg Rohrsysteme GmbH

in 31515 Wunstorf, Germany

2018-04-11

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this report contains 14 pages

Content

1. Procedure and task

Brugg Rohrsysteme GmbH (Brugg) orders from Fernwärme-Forschungsinstitut GmbH (FFI) to carry out tensile tests for FLEXWELL- district heating cable (FHK) in dimension 200/310. Intension of the tests is the verification of a remaining plastic deformation < 1 % (1 % yield strength) for tensile forces up to 100 kN. Measurement data on tensile force and strain have to be logged during the tests.

2. Test material

Three approximately 2,5m long FHK-test pipes with mounted tensile adapters on both sides will be delivered to FFI on 2018-08-07 /**Figure 1**/. The FFI-internal sample numbers 4844, 4845 and 4846 will be assigned to the test pipes.

Figure 1 FHK-test pipes in delivery state

The test pipes are carrying the following markings on the casing:

Test pipe **4844**:
030555999 BRUGG FLEXWELL-Fernheizkabel FHK 200/310 1.4301 212m

Test pipe **4845**:
030555999 BRUGG FLEXWELL-Fernheizkabel FHK 200/310 1.4301 231m

Test pipe **4846**:

030555999 BRUGG FLEXWELL-Fernheizkabel FHK 200/310 1.4301 228m

The tensile adapters are carrying the following unit markings.

At casing sheet: -S- 111468 FHK 200/310 080-25-008 A

At service pipe adapter: -S- 111468 FHK 200/310 054-00-063 A

3. Test set-up

For the performance of the tensile tests, the test pipes will be connected by a M 36 threaded bar to a hydraulic cylinder on the pulling side. There's also a load cell mounted between cylinder and threaded bar. The test pipe is placed in a pressure pipe which retains against the fixing unit of the hydraulic cylinder.

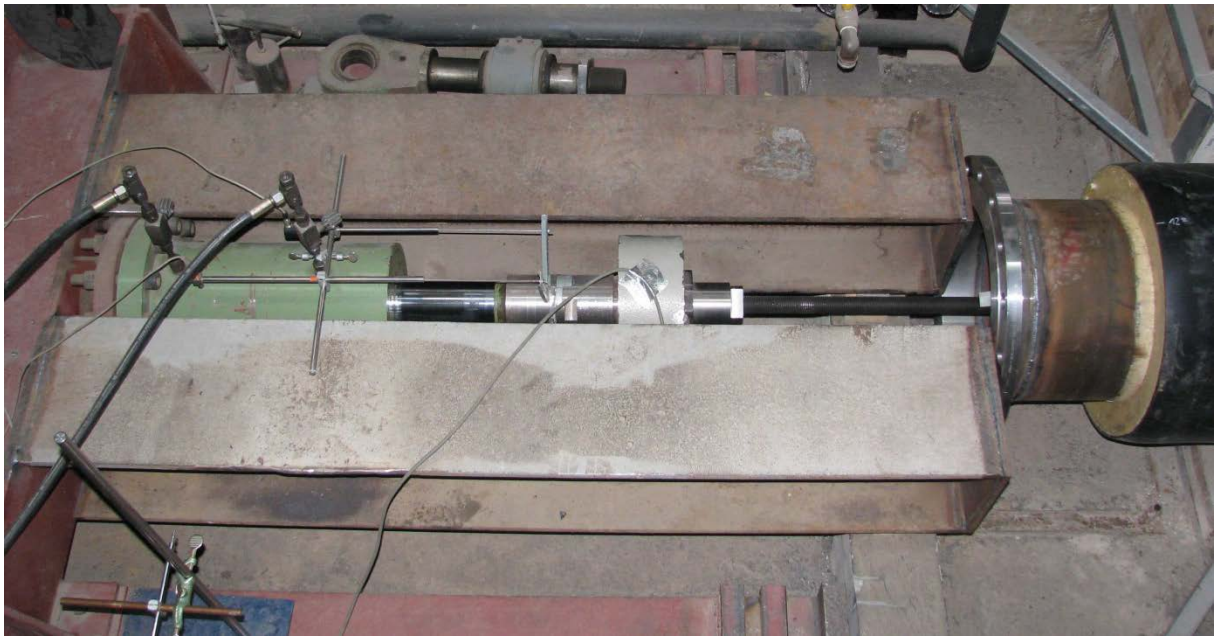

Figure 2 Pulling side of test set-up

On the opposite side the tensile adapter is connected to the pressure pipe by M 36 threaded bar and blind flange coupling.

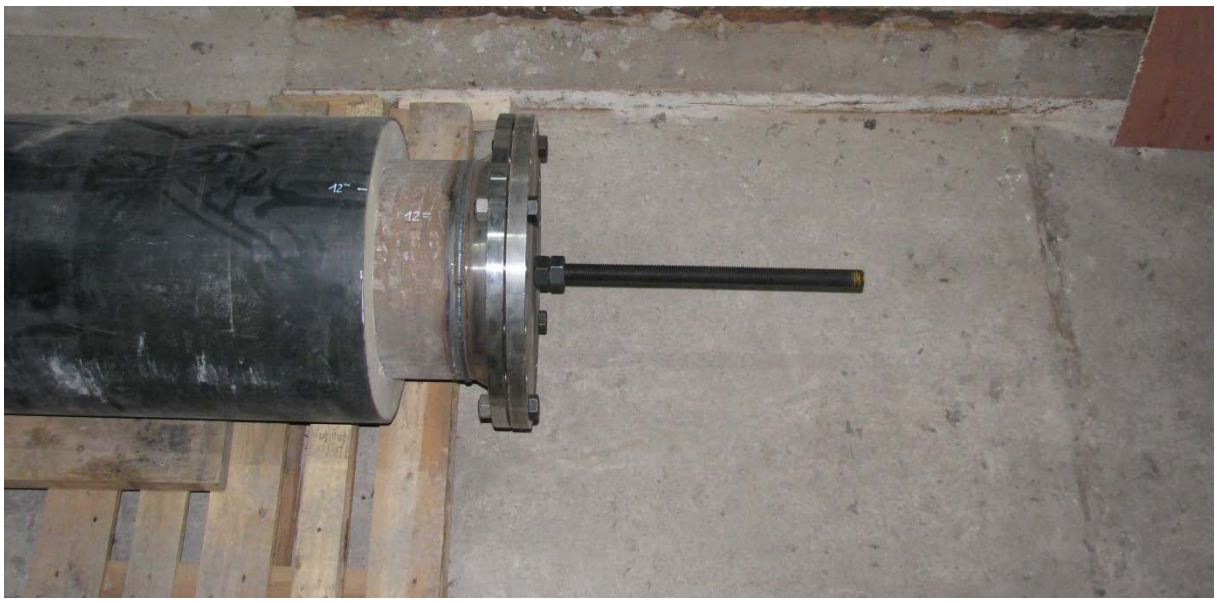

Figure 3 Opposite side of test set-up

The following measurement equipment will be used for logging data on tensile force and strain:

Datalogger:	Ahlborn Almemo MA28909, Ser.Nr.: H11090305
Load sensor:	HBM Z4 (50t), F.Nr.: C49136
Displacement transducer:	Micro Epsilon LVP-200-ZA-SR7-I, SN:1101

In order to determine tensile force dependent self-strains of the test unit a zero measurement will be carried out previous to the tensile tests. The results are documented graphically in the following diagram. An additional correction of the measurement data for the test pipes will be done with these data.

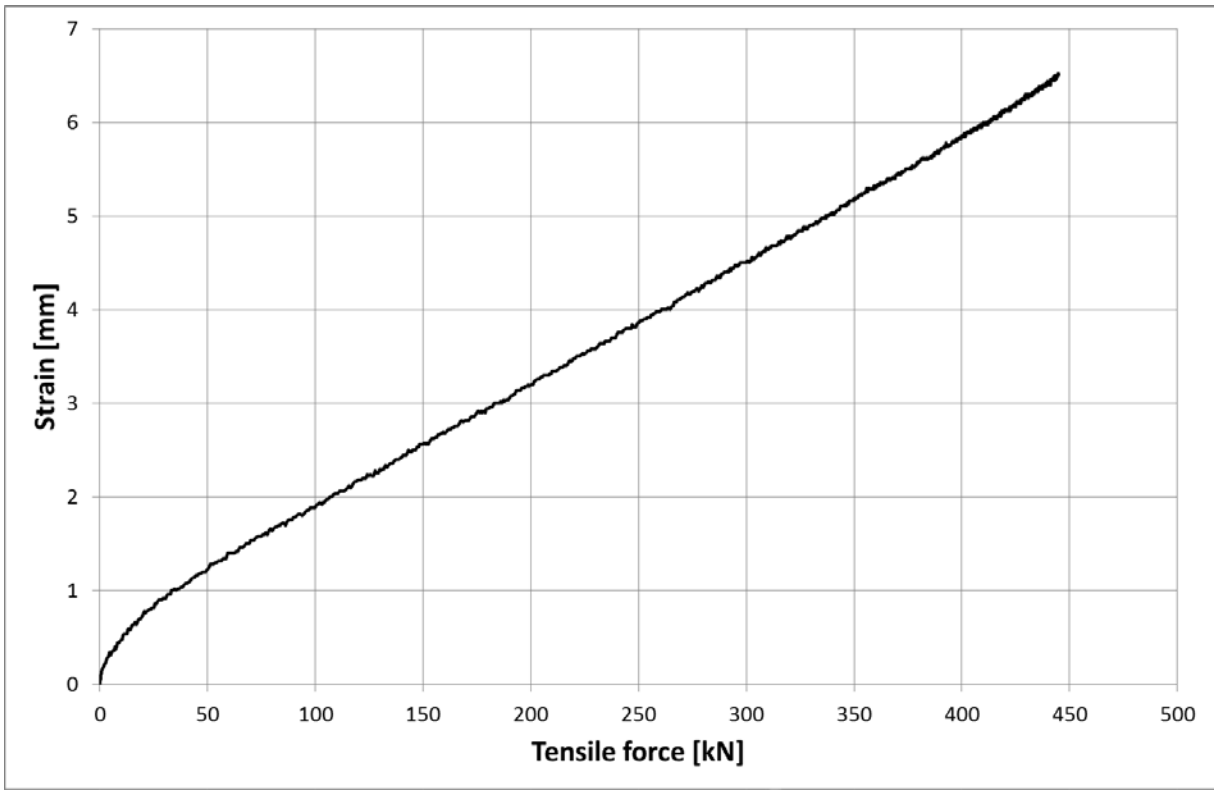

Diagram 1 Tensile force dependent self-strain of the test unit

4. Test procedure and measuring data

The test pipes will be initially checked concerning their length within the framework of the test procedure. Here, the total length will be measured. Twice the length of service pipe adapter has to be subtracted to calculate the length of FHK pipe. The length of service pipe adapter is specified with 132,5 mm by the customer. The following values are resulting:

Table 1 Initial length of the test pipes

test pipe FHK	total length [mm]	FHK-length [mm]
4844	2.758,5	2.493,5
4845	2.761,0	2.496,0
4846	2.765,8	2.500,8

The target tensile velocity is uniformly fixed to 10 mm/min for all three tests.

The corrected measurement data for the first tensile test (4845) is graphically documented in the following diagram.

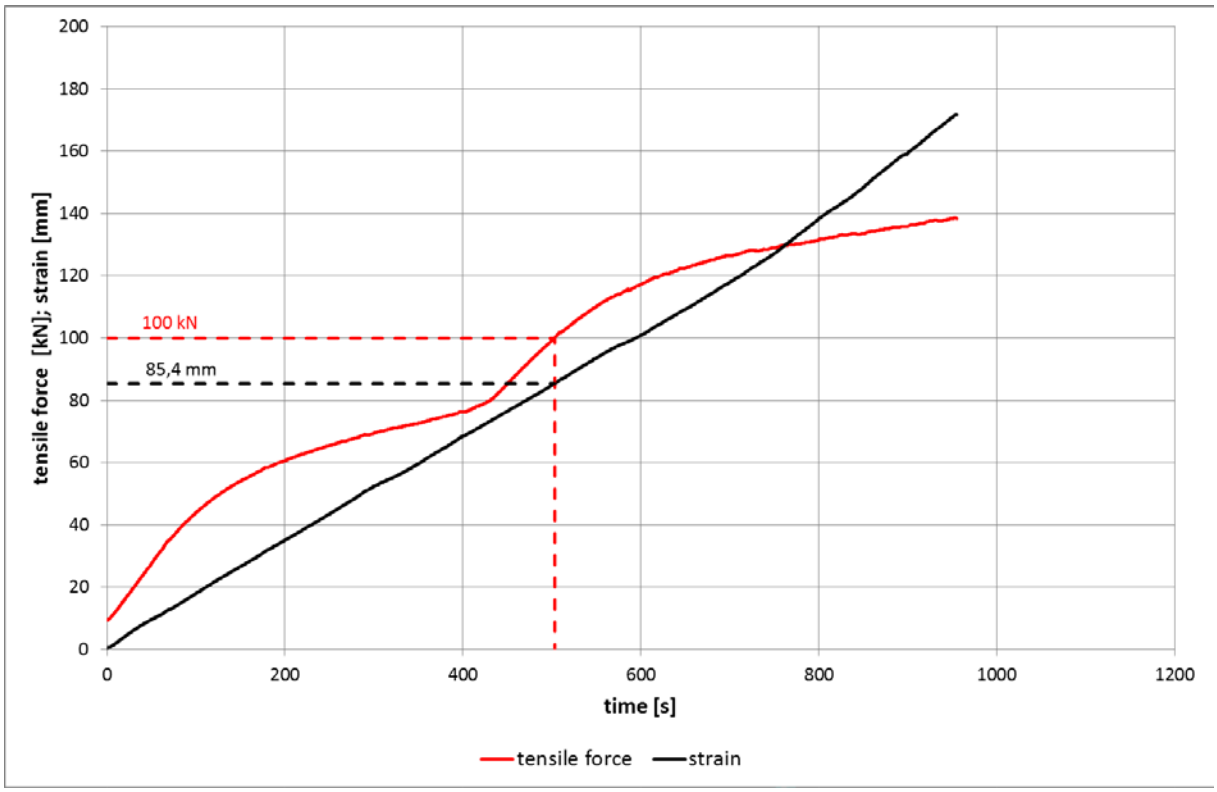

Diagram 2 Measurement data of first tensile test (4845)

The tensile force shows a nearly linear gradient from the beginning up to approx. 40 kN and changes on a diminishing scale from (40÷80) kN. The tensile gradient obviously will be changed by a firstly unknown effect then. Between (80÷100) kN the tensile force increases nearly linear again. Between (100÷125) kN the gradient is on a diminishing scale again. The tensile force increases linear above approx. 125 kN up to the end of test. The maximum tensile force at the end of test is 138,6 kN.

After unloading and dismounting of test pipe the total length will be measured to 2.875,5 mm which means the calculated FHK-length is 2.610,5 mm. The permanent total strain is 117,0 mm for this test. The percentage permanent strain is 4,2 % related to the total length and accordingly 4,7 % related to the FHK-length.

A displacement between service pipe adapter and casing sheet will be detected on the tensile adapters after dismounting of the test pipe. Obviously, there has been a gap between the components in initial state. The position is marked with “X” in /**Figure 4**/. Thus, the service pipe firstly strains and therefore enlarges dimension “a”. Against this background, the force curve for the tensile test becomes more understandable.

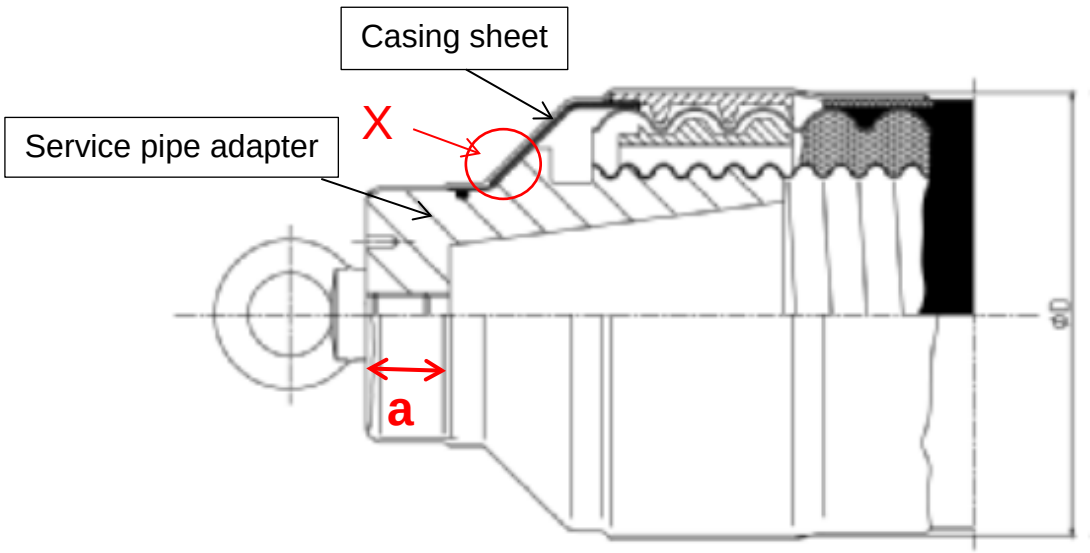

Figure 4 Schematic view of the tensile adapter [source: Brugg Rohrsysteme GmbH]

The following diagram documents the corrected measurement data of the second tensile test (4846).

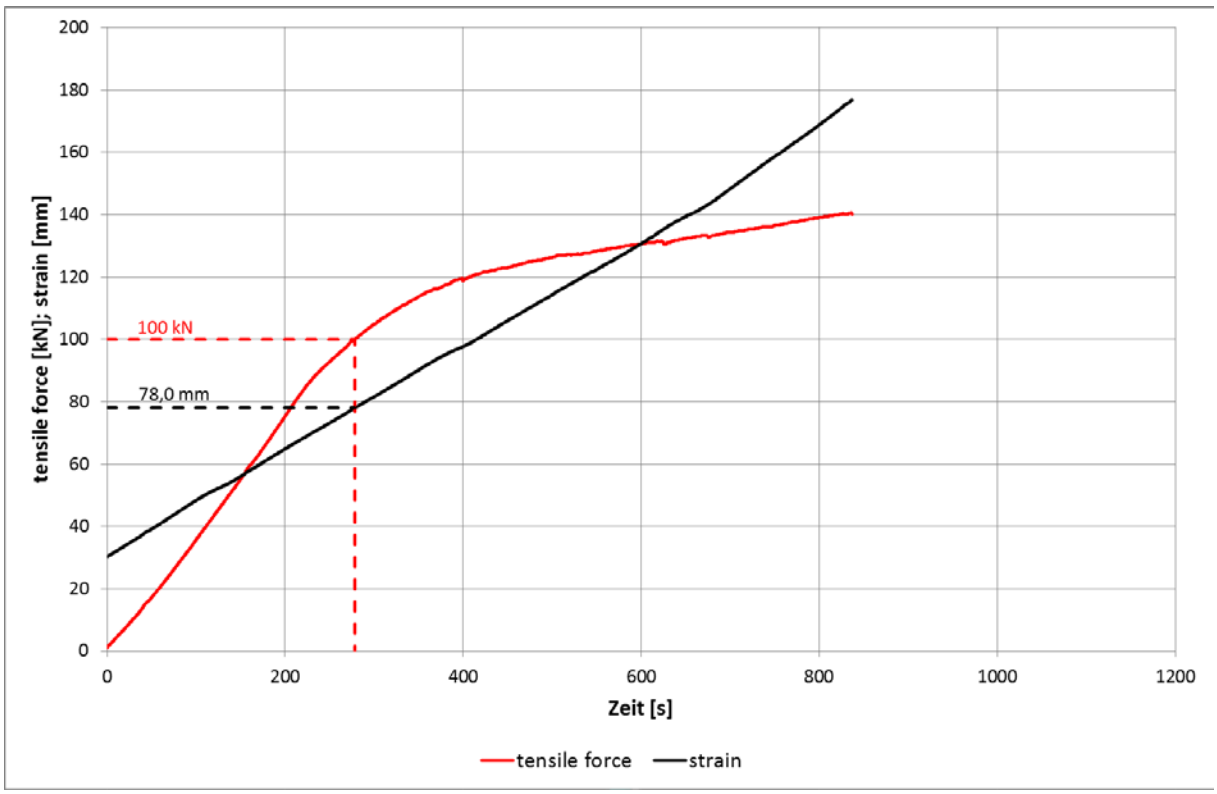

Diagram 3 Measurement data for the 2. tensile test (4846)

Because a horizontal directional drilling is always characterized by a cyclic tensile progression, the force was applied cyclically in the tensile test of the second sample. For this purpose, the first strain was stopped at 54 mm and the test pipe unloaded. Thereafter, the test pipe has a permanent pre-strain of 30,2 mm. /Diagram 3/ documents the second tensile strain. Due to the pre-straining the force curve results in a more steady gradient. In contrast to the first tensile test, no significant influence of the tensile adapters can be seen. The maximum tensile force at the end of the test is 140,6 kN.

The measurement data for the second tensile test will not be adopted for the test interpretation because of the pre-straining. As in the first test, the tensile force above approx. 125 kN has a nearly linear course.

After unloading and dismounting of test pipe the total length will be measured to 2.889,0 mm which means the calculated FHK-length is 2.624,0 mm. The permanent total

strain is 128,0 mm for this test. The percentage permanent strain is 4,6 % related to the total length and accordingly 5,1 % related to the FHK-length.

After the influence of the tensile adapters already has been determined in the first test, the dimension “a” (see **Figure 4**) was measured before and after the test. The difference of the measurements for “a” before and after the test yields values of ∆a1 = 16,0 mm and ∆a = 24,1 mm. In relation to the whole test pipe results in a total value of ∆a = 40,1 mm for two installed tensile adapters.

The following diagram documents the corrected measurement data of the third tensile test (4844).

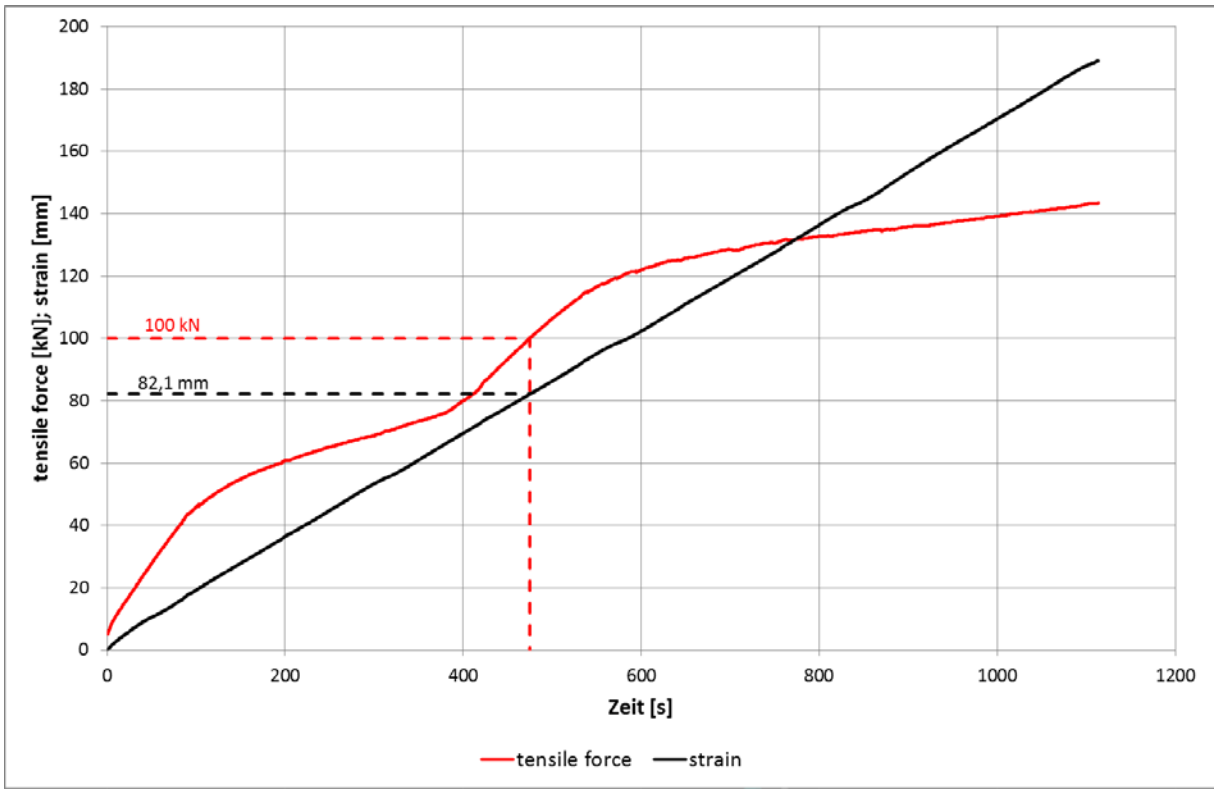

Diagram 4 Measurement data for the 3. Tensile test (4844)

The force progression of the third tensile test corresponds qualitatively to that of the first tensile test. The maximum tensile force at the end of the test is 143,4 kN.

After unloading and dismounting of test pipe the total length will be measured to 2.901,3 mm which means the calculated FHK-length is 2.636,3 mm. The permanent total strain is 135,5 mm for this test. The percentage permanent strain is 4,9 % related to the total length and accordingly 5,4 % related to the FHK-length.

The difference of the measurements for “a” before and after the test results in values of $\Delta a1 = 19{,}0$ mm, $\Delta a2 = 22{,}5$ mm and $\Delta a = 41{,}5$ mm.

5. Evaluation of the tensile tests

With regard to an evaluation of the test results, the question of the permissible tensile forces for trenchless laying of FLEXWELL district heating cable –FHK- is of central importance. These have to be limited particularly with respect to plastic deformations appearing at higher forces. For this purpose, a plastic deformation of 1 % must not be exceeded. Next, the tensile forces which lead to such a strain are to determine. The following diagram shows the gradients of tensile force for test 1 and 3 as a function of relative strain. A described in chapter 4, due to the deviating test procedure, the second tensile test is not taken into account in this evaluation. However, this test shows, that no significant deviation between a linear force progression and a cyclic force progression has to be expected for the remaining deformation of this type of pipeline.

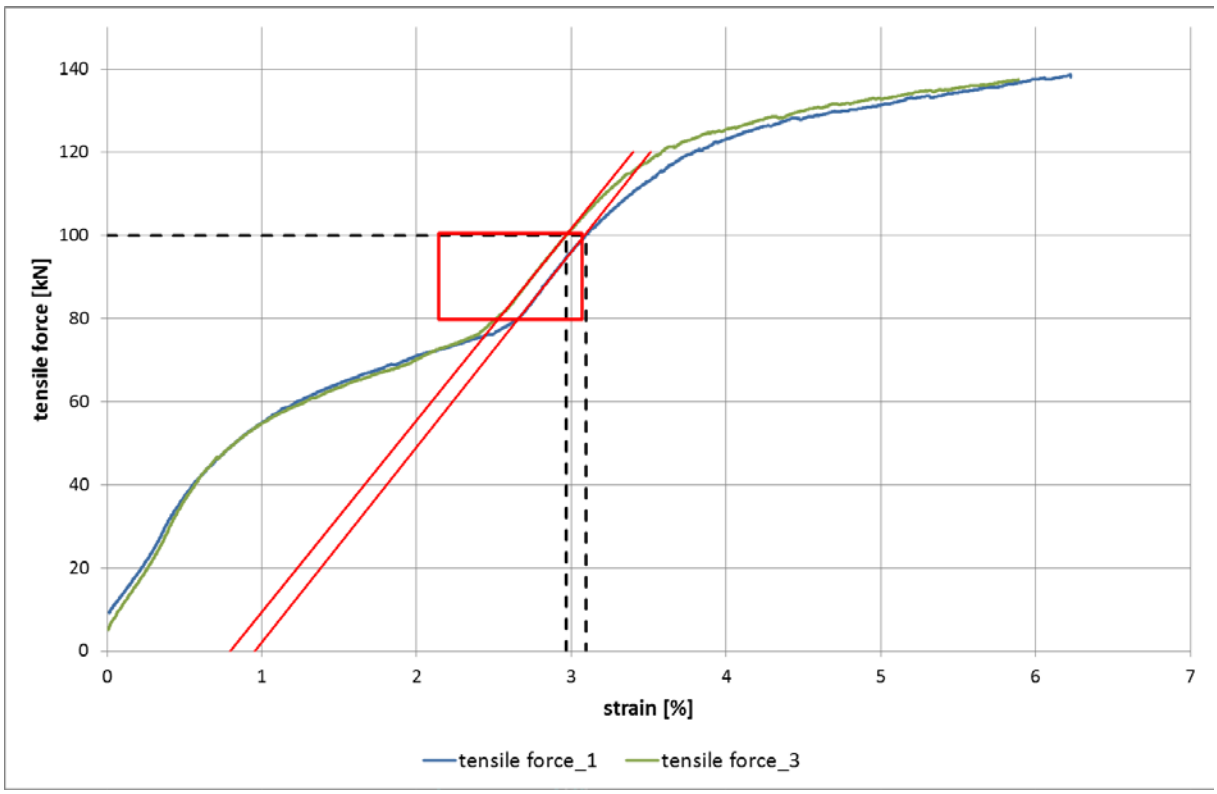

Diagram 5 Comparison of measurement data for tensile test 1 and 3

Based on the curve progressions of both tensile tests, it can be assumed that there is a mixed strain in the range up to 80 kN. First of all the compensation of the described gaps in the tensile adapters (Δa1, Δa2, resp. Δa) is important.

Of particular interest, therefore, are the courses of tensile test 1 and 3 in the range of approx. (80÷100) kN. In this range the test pipes will be pulled as a bonded system and there is a nearly linear correlation between strain and tensile force. This proportional range therefore represents the upper range of linear-elastic strain of complete system. Under this condition, the behavior of complete system in the range ≤ 100 kN can be described linearized, as documented in the following diagram.

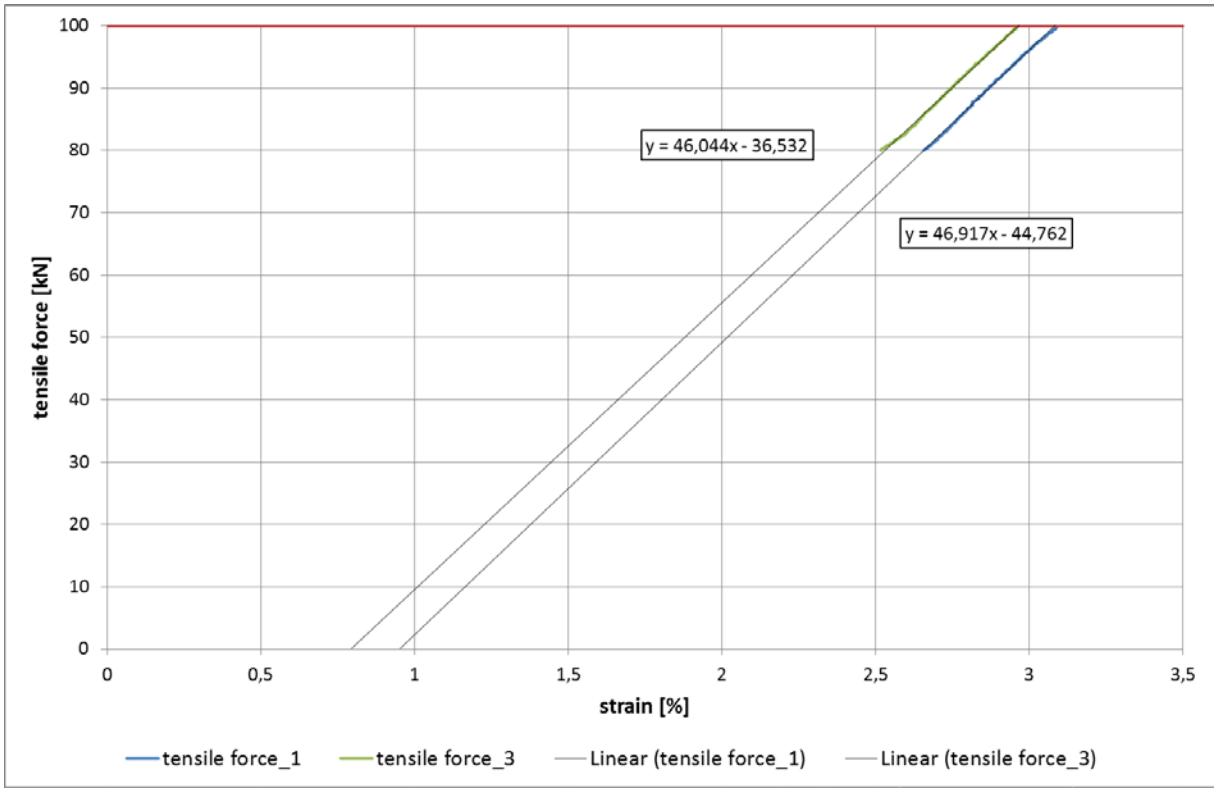

Diagram 6 Detail of measurement data for tensile test 1 and 3

/Diagram 6/ includes a linear extrapolation for tensile test 1 and 3 in the measurement data range (80÷100) kN. Also given in the diagram are the corresponding linear equations. The calculated intersections of the linear equation with the abscissa (x-axis) are at 0,95 % for tensile test 1 and 0,79 % for tensile test 3. At 100 kN the strain is 3,09 % for test pipe 1 and 2,97 % for test pipe 3. It results an elastic strain part of approx.. 2,1 %. This is the area between the intersection of the linear line with the abscissa and the 100 kN limit line.

For test pipe 3 the value is 2,2 %. Conversely, the strain of test pipe 1 at a tensile force of 100 kN includes a plastic deformation of 1%. The value for test pipe 3 is 0,95 %. Based on the experimental data, it can be concluded that the plastic deformation part at a maximum tensile force of 100 kN is below one percent.