STEELS FOR CONCRETE REINFORCEMENT:
TENSILE TESTING OF BARS

1. SCOPE

This NORDTEST method describes a procedure for tensile testing of reinforcing steel in order to determine specified mechanical properties.

2. FIELD OF APPLICATION

This method applies to all types or grades of non-prestressing reinforcing steels including welded fabrics.

3. REFERENCES

NORDTEST NT MECH 001 - Testing machines: Calibration
NORDTEST NT MECH 005 - Determination of diameter and cross-sectional area of bars
ISO - Verification of extensometers used in uniaxial testing.
DIN 862 - Slide caliper

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4. SYMBOLS AND DEFINITIONS

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<td>G</td>
<td>mass by length m/l</td>
<td>kg/m</td>
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<tr>
<td>m</td>
<td>mass of test piece</td>
<td>kg</td>
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<tr>
<td>l</td>
<td>length of test piece</td>
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<tr>
<td>d</td>
<td>diameter of test piece</td>
<td>mm</td>
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<tr>
<td>d_n</td>
<td>nominal diameter of test piece</td>
<td>mm</td>
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<tr>
<td>d_c</td>
<td>circular core diameter of test piece excl ribs</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>d_g</td>
<td>equivalent diameter $12.74 \sqrt{G}$</td>
<td>mm</td>
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<tr>
<td>S</td>
<td>cross-sectional area $\frac{\pi \cdot d^2}{4}$</td>
<td>mm²</td>
<td></td>
</tr>
<tr>
<td>S_f</td>
<td>cross-sectional area of longitudinal ribs</td>
<td>mm²</td>
<td></td>
</tr>
<tr>
<td>S_n</td>
<td>nominal cross-sectional area $\frac{\pi \cdot d_n^2}{4}$</td>
<td>mm²</td>
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</tr>
<tr>
<td>S_c</td>
<td>circular core area $\frac{\pi \cdot d_c^2}{4}$</td>
<td>mm²</td>
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</tr>
<tr>
<td>S_k</td>
<td>total core area $S_c + S_f$</td>
<td>mm²</td>
<td></td>
</tr>
<tr>
<td>S_g</td>
<td>equivalent cross-sectional area $127.4 \sqrt{G}$</td>
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<td></td>
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<td>L</td>
<td>gauge length</td>
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<td>extensometer gauge length</td>
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<td>L_o</td>
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<td>final gauge length after fracture</td>
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<tr>
<td>F</td>
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<td>N</td>
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<td>F_e</td>
<td>force at specified yielding (yield force)</td>
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<td>F_p0,2</td>
<td>force at specified non-proportional elongation (here exemplified as 0,2%)</td>
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<td>(here exemplified as 0,5%)</td>
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<td>F_eH</td>
<td>force at upper yield-limit</td>
<td>N</td>
<td>2-4</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
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<tr>
<td>$F_{eL}$</td>
<td>force at lower yield-limit</td>
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<td>2-4</td>
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<tr>
<td>$F_m$</td>
<td>maximum force</td>
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<tr>
<td>$f$</td>
<td>ratio between yielding force and maximum force $F_e/F_m$ (yield ratio)</td>
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<tr>
<td>$R$</td>
<td>stress</td>
<td>N/m$^2$</td>
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<tr>
<td>$R_e$</td>
<td>stress at specified yielding (yield stress)</td>
<td>N/m$^2$</td>
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<td>$R_{p0,2}$</td>
<td>proof-stress at specified non-proportional elongation $F_{p0,2}/S$</td>
<td>N/m$^2$</td>
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<tr>
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<tr>
<td>$R_m$</td>
<td>tensile strength $F_m/s$</td>
<td>N/m$^2$</td>
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<tr>
<td>$A_{LO}$</td>
<td>percentage elongation after fracture</td>
<td>%</td>
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<td>$L_0 - L_o$</td>
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<td>$L_o$</td>
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<td></td>
<td>$100$</td>
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<td>$A_{LO/2}$</td>
<td>percentage elongation after fracture using the gauge length $A_{LO}$ divided by two</td>
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<tr>
<td>$A_g$</td>
<td>percentage non-proportional elongation</td>
<td>%</td>
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<tr>
<td>$A_{g1}$</td>
<td>percentage uniform elongation after fracture, clause 5.14</td>
<td>%</td>
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<td>$A_{g2}$</td>
<td>percentage uniform elongation after fracture, clause 5.15</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>$A_5$</td>
<td>percentage elongation after fracture</td>
<td>%</td>
<td></td>
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<tr>
<td></td>
<td>$L_0 = 5 \ d = 5.65\sqrt{S} = \frac{5\sqrt{4} \ S}{\pi}$</td>
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<tr>
<td>$A_{10}$</td>
<td>percentage elongation after fracture</td>
<td>%</td>
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<tr>
<td></td>
<td>$L_0 = 10 \ d = 11.3\sqrt{S} = \frac{10\sqrt{4} \ S}{\pi}$</td>
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<tr>
<td>$A_{200mm}$</td>
<td>percentage elongation after fracture at non-proportional gauge length (here exemplified as $L_0 = 200 \ mm$)</td>
<td>%</td>
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</table>
5. METHOD OF TESTING

5.1 Principle

The test consists of straining a test piece by tensile force generally to fracture, for the purpose of determining one or more of the mechanical properties defined in clause 4.

The test is carried out at ambient temperature 23 ± 5 °C unless otherwise specified.

The testing shall be carried out by qualified persons. If computerized testing is used the program shall be well documented.

5.2 Apparatus

The testing equipment shall be calibrated with traceability to international standards at least once a year and in between with regular internal inspection (measurement of a single point or check out of the calibration signal).

For tensile testing machines it is recommended to do the calibration in accordance with the procedure described in NORDTEST NT MECH 001.

Tensile testing machine with adjustable cross-head speed and equipped with force measuring device. Inaccuracy shall be less than ± 1 % (class 1).

Extensometer with adjustable gauge length. Inaccuracy shall be less than ± 1 % (class 1).

Equipment for marking the original gauge length $L_0$. Inaccuracy shall be less than ± 1 %.

*Slide caliper* for length measurement. Inaccuracy shall be less than ± 1 %.
5.3 **Test piece**

From bars or welded fabrics a test piece with sufficient length is cut or sawn.

The test piece is to be tested in full section (unmachined).

**Recommended length:**

- 500 mm for $d < 16$ mm
- 700 mm for $d > 16$ mm

5.4 **Diameter and cross-sectional area**

For the determination of mechanical properties of the material the nominal cross-sectional area shall be used if not otherwise specified in the product standard. In those cases the cross-sectional area shall be determined according to one of the methods described in NORDTEST NT MECH 005.

5.5 **Artificial ageing**

If the material according to the product standard shall be aged the procedure is as follows. The test piece is heated to +250 °C and kept at this temperature for at least half an hour (0,5 h) and not longer than one hour (1 h), followed by free cooling in air to ambient temperature.

As option the artificial ageing may be performed at +100 °C, for at least two hours (2 h), in still air furnace or half an hour (0,5 h) in boiling water followed be free cooling in air to ambient temperature.

5.6 **Marking of the original gauge length $L_0$**

For the determination of elongation, the original gauge length shall be marked by means of fine marks, scribed lines or by fine punch marks at precise intervals for instance 5 mm or 10 mm.

The marks must not cause any premature fracture of the test piece.
5.7 **Method of gripping**

The test piece shall be clamped in the grips in such a way that the force is applied as axially as possible. If a one-sided extensometer is used the axiality must be verified.

5.8 **Cross-head speed**

Unless otherwise specified in the product standard, the speed of the cross-head shall comply with the following requirements. For the determination of yield stress or proof stresses the rate of stressing shall be between 3-30 N/mm² s⁻¹ or the rate of straining between 0.000015 s⁻¹ and 0.00015 s⁻¹.

If the force measuring system is using a pendulum the rate of stressing can be increased by a factor of 3 if it is clearly shown that a minimum of energy is stored in the frame.

In the plastic range, after leaving the yield zone the speed of the cross-head may be increased to maximum 50 % per minute of the original free length between the grips.

5.9 **Yield stress**

When testing a material with a distinct yield zone (Fig. 2 and 3) the force at upper yield limit and sometimes the lower yield limit is determined with a recorder, analog force measuring device or by a microprocessor (computer). When using a recorder the upper and/or lower yield stress is determined from the force - elongation diagram, where the first upper peak immediately before reaching the yield zone is the force at upper yield, and the lowest peak throughout the yield zone, is the force at the lower yield.

In both cases transient effects must be ignored (Fig. 2 and 3).

When testing material with a distinct yield limit but without a yield zone (Fig. 4) the yield is determined when using a recorded diagram to be the breakpoint of the curve. In many cases the yield can be determined with sufficient accuracy by direct reading from an analog force measuring device.
Fig. 1. Stress strain diagram (in practice force-elongation)

Fig. 2. Force elongation diagram for determination of upper and/or lower yield stress

Fig. 3. Force elongation diagram for determination of upper and/or lower yield stress

* single dip in the curve must be left without notice
5.10 Determination of proof stress $R_p$ (non-proportional elongation)

The force at proof stress $R_p$ is determined by using a recorder and drawing a force-elongation curve as shown in Fig. 5.

A line AB is drawn parallel to OC, at a distance corresponding to the prescribed elongation value, for instance 0.2 %, when determining $R_{p0.2}$. The ordinate for intersecting point Q will give the force $F_{p0.2}$ which corresponds to proof stress $R_{p0.2}$. Sometimes it is difficult to see from the diagram the direction of line OC. In those cases the lines OC and AB could be drawn on the basis of a known or agreed, value of the modulus of elasticity. It is also allowed to use the method shown in Fig. 6. The line AB is drawn parallel to the center line in a hysteresis curve, which you get from unloading and loading to the same point.
5.11 Permanent set stress \( R_f \)

5.11.1 Determination of permanent set stress

The test piece is loaded and unloaded alternately. After each unloading the permanent percentage elongation is measured with an extensometer. Each force shall be greater than the previous. This procedure is continued until the force reached corresponds to the prescribed percentage elongation. Last step shall not be greater than 10% of the prescribed percentage elongation. Corresponding stress is the proof stress of the material. Each individual force shall remain 10-12 sec (Fig. 7).

5.11.2 Verification of permanent set stress

The test piece is subjected to a force for 10-12 sec corresponding to the specified yield stress. It is then confirmed, after unloading, that the permanent set elongation is not more than the percentage specified for the original gauge length (Fig. 8).
Fig. 7. Force elongation diagram when determining permanent set stress $R_r$.

Fig. 8. Force elongation diagram when verifying permanent set stress $R_r$.

Fig. 9. Force elongation diagram when determining proof stress $R_t$. 
5.12 Determination of proof stress $R_t$ (total elongation)

5.12.1 Graphical method

The proof stress (total elongation) is determined on the force/elongation diagram by drawing a line parallel to the ordinate axis (force axis) and at a distance from this equivalent to the prescribed total percentage elongation. The point $Q$ at which this line intersects the curve gives the force $F_t$ corresponding to the proof stress, (Fig. 9).

5.12.2 Direct reading

The proof stress (total elongation) can also be determined by direct reading of an elongation measuring device mounted on the test piece. When the elongation has reached the prescribed value the force of the testing machine divided by the original cross-sectional area is the proof stress (total elongation) of that test piece.

**Note:** This property may be obtained without plotting the force/elongation diagram by using appropriate devices (microprocessor etc).

5.13 Determination of percentage elongation after fracture $A_{Po}$

5.13.1 Normal case

For the determination of the percentage elongation after fracture the test piece shall have the original gauge length $L_0$ marked before testing.

After fracture the two parts of the test piece are carefully fitted back together so that their axies lie in a straight line.

Special precautions shall be taken to ensure proper contact between the broken parts of the test piece when measuring the final gauge length $L_u$. This is particularly important in the case of test pieces having low elongation values. The change in the gauge length is measured to the nearest 0.1 mm and the value of the percentage elongation after fracture is rounded off to the number of significant figures stated in the product standard.
The final gauge length, $L_u$, after fracture is measured over the rupture. This measurement is, in principle valid only if the distance between the rupture and the nearest end mark is not less than $1/3 L_u$. However, the measurement is valid irrespectively of the position of the fracture if the percentage elongation after fracture reaches the specified value.

Notes:

1. When using an extensometer to measure the elongation after fracture and the total elongation at fracture, the extensometer gauge length $L_e$ must be equal to the original gauge length $L_o$.

2. If machines capable of measuring elongation automatically are used, gauge marks are unnecessary. The elongation measured is the total elongation; it is therefore necessary to deduct the percentage elastic elongation in order to obtain the percentage elongation after fracture unless the machine does this automatically.

5.13.2 Special case

To avoid having test pieces rejected when the position of the fracture does not comply with the conditions of 5.13.1 the following method may be used, by agreement.

a) before the test, sub-divide the original gauge length $L_o$ into $n$ equal divisions.

b) after the test, use the symbol $X$ to denote the end gauge mark of the shorter piece and the symbol $Y$ to denote the gauge mark for the same number of divisions shown on the longer piece (Fig. 10 and 11).

Fig. 10. Measurement of elongation, even parts
Fig. 11. Measurement of elongation, odd parts.

The missing number of divisions (i.e. the number of divisions beyond the distance x y which is included in the original gauge length) could be even or odd.

If the number of missing divisions is even the measurements shall be performed according to Fig. 10. The graduation mark Z is chosen so that the distance YZ covers exactly half the number of the missing divisions. For the calculation of the final gauge length \( L_u \) a distance YZ is assumed to be set outside the graduation mark X (to the left in Fig. 10). The final gauge length \( L_u \) will than be
\[
L_u = XY + 2YZ = XZ + YZ
\]
It is advisable to measure XZ and YZ separately.

If the number of missing divisions is odd, the measurements shall be performed according to Fig. 11. The graduation marks Z and W are chosen so that the distance between them is one division and the distances YZ and YW together covers the missing number of divisions. The final gauge length \( L_u \) will than be
\[
L_u = XY + YZ + YW = XZ + YW
\]

Note: If the percentage elongation after fracture calculated according to this clause does not comply with the requirements in the relevant product standard the test should be cancelled and a new one performed.

Fig. 12. Measurement of total elongation \( A_{gt} \).
5.14 Percentage non-proportional elongation \( A_g \) at maximum force

The percentage non-proportional elongation shall be measured after unloading.

5.14.1 Percentage uniform elongation \( A_{g1} \) after fracture

The determination can only be done on test pieces after fracture and with an original gauge length more than \( 10 \times d_n \) and at least 100 mm. The test piece shall before testing be devided into equal divisions. A graduation mark close to the rupture on the longer piece is marked 0.

The number of divisions which corresponds to \( 1/4 \) of the gauge length \( L_o \) is counted from 0 to the graduation mark E. The same number of divisions is then counted from E to F, Fig. 12. The distance EF is measured and the percentage non-proportional elongation at maximum force is calculated using the equation

\[
A_{g1} = \left( \frac{4EF - L_o}{L_o} \right) \times 100
\]

5.14.2 Percentage uniform elongation \( A_{g2} \) after fracture

The two elongations \( A_{L_o} \) and \( A_{L_o/2} \) shall be determined. The original gauge length \( L_o \) shall be at least \( 20 \times d_n \) when testing bar and wire with diameter less than 16 mm and at least \( 10 \times d_n \) when testing larger diameters. The uniform elongation is calculated using the equation \( A_{g2} = 2A_{L_o} - A_{L_o/2} \).

5.15 Determination of percentage total elongation \( A_{gt} \) at maximum force

An extensometer with a gauge length \( L_e \) shall be fitted to the test piece. The gauge length shall normally be 200 mm. The increase in the gauge length \( L_e \) shall be read on the extensometer at the maximum force \( F_m \). After the extensometer has been removed, the test piece shall be loaded to fracture. Fracture shall take place within the gauge length. If this is not the case, the test shall be cancelled if the value of the total elongation, does not comply with the requirements in the relevant product standard.
To avoid damage on the extensometer if can be removed after the yielding is fullfilled and replaced by other methods of length measurements until maximum force has been reached.

6. TEST RESULTS

The values recorded from the test for each mechanical property required in the product standard shall be stated with the relevant number of significant figures.

7. TEST REPORT

The test report shall include the following information if relevant:

a) Name and address of the testing laboratory
b) Identification number of the test report
c) Name and address of the organization or the person who ordered the test
d) Purpose of the test
e) Method of sampling and other circumstances (date and person responsible for the sampling)
f) Name and address of manufacturer or supplier of the tested object
g) Name or other identification marks of the tested object
h) Type, grade and dimensions of tested object
i) Date of supply of the tested object
j) Date of the test:
k) Test method
l) Conditioning of the test specimens; environmental data during the test (temperature, pressure, RH, etc)
m) Identification of the test equipment and instruments used
n) Any deviations from the test method
o) Test results (use SI units)
p) Inaccuracy or uncertainty of the test result
q) Conclusion
r) Date and signature