STEELS FOR CONCRETE REINFORCEMENT: AXIAL LOAD FATIGUE TESTING OF BARS

Key word: Concrete, building material, bars

1 SCOPE
This NORDTEST method describes a procedure for fatigue testing under axial loading to obtain the fatigue strength of reinforcing steel in the fatigue regime where the strains are predominately elastic both upon initial loading and throughout the testing.

2 FIELD OF APPLICATION
This method applies to all types or grades of reinforcing and prestressing steels.

3 REFERENCES
NORDTEST NT MECH 001 - Testing machines: Calibration
NORDTEST NT MECH 005 - Determination of diameter and cross-sectional area of bars.
ISO 4965 - Axial load fatigue testing machines - Dynamic force calibration - Strain gauge technique.

4 SYMBOLS AND DEFINITIONS

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<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Unit</th>
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<tr>
<td>( \sigma_{\text{min}} )</td>
<td>Minimum stress</td>
<td>N/mm²</td>
</tr>
<tr>
<td>( \sigma_{\text{m}} )</td>
<td>Mean stress (steady component of stress)</td>
<td>N/mm²</td>
</tr>
<tr>
<td>( \sigma_{a} )</td>
<td>Stress amplitude (variable component of stress)</td>
<td>N/mm²</td>
</tr>
<tr>
<td>( \sigma_{\text{max}} )</td>
<td>Maximum stress</td>
<td>N/mm²</td>
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\[ \sigma_{\text{m}} = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2} \]
See Fig 1

\[ \sigma_{a} = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2} \]
See Fig 1

\[ 2\sigma_{a} = \sigma_{\text{max}} - \sigma_{\text{min}} \]
See Fig 1
<table>
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| $R_b$  | Stress ratio
        | The algebraic ratio of the minimum stress to the maximum stress in one cycle
        | $R_b = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}}$ |
| $f$    | Frequency
        | The number of cycles per time unit |
| $n$    | Number of the stress cycles endured
        | The number of cycles of a specified character (that produce fluctuating stress and strain) which a specimen has endured at any time |

| N     | Number of stress cycles to failure
        | The total number of cycles which a specimen withstands during a fatigue testing |
| $\sigma_N$ | Fatigue strength at N cycles
        | A theoretical value of stress for failure at exactly N cycles as determined from a $\sigma$-$N$ diagram. The value of $\sigma_N$ thus determined is subject to the same conditions as those which apply to the $\sigma$-$N$ diagram |
| $\sigma_D$ | Fatigue limit
        | The limiting value of the median fatigue strength as N becomes very large |

Fig 1 Fatigue stress cycle
5 METHOD OF TESTING

5.1 Principle
The test is performed by exposing a test specimen either to an axial tensile or an axial compressive load to a prescribed mean value ($\sigma_m$) and then alternate between a maximum and a minimum peak value. The wave shape is normally sinusoidal. The axial load fatigue testing is used to determine the effect of component geometry, surface conditions, stress, etc, on the fatigue resistance of reinforcing and prestressing steel bars and wires subjected to cyclic stress for a relatively large number of cycles.

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 documented.

5.2 Apparatus
Fatigue testing machine

Generally the tests will be performed on one of the following types of fatigue testing machines:
A. Hydraulic, electrohydraulic or servohydraulic.
B. Electromechanical or magnetically driven.
C. Mechanical (eccentric crank, power screws, rotating masses).

The action of the machine should be analyzed to ensure that the desired form and magnitude of loading is maintained for the duration of the test.

The testing machine shall be calibrated in static mode according to NORDTEST NT MECH 001 and the inaccuracy shall be not greater than ±1 % (class 1).

Dynamic force calibration of the machine shall be performed according to ISO 4965.

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

5.33 Test specimen preparation
The preparation of the test specimen depends on the objective of the test program, type of testing machine and the form in which the material is available. The design of the test specimen shall be such that failure occurs in the test section. The ratio of the cross-sectional areas (test section to gripping section) is dependent on the gripping method. Plain bars may be tested without preparation of gripping section.

The test specimen shall have a minimum free length of 10 $d$ between the grips, where $d$ is the nominal diameter of the specimen.

Note Detailed information about the test specimen is normally stated in the relevant product standard.

Gripping method A
This method can be used for all types of gripping devices in all types of fatigue testing machines.
Reduce the diameter over the gripping length of the test specimen by about 1 mm and with a transition radius to the test section between 1 and 5 mm.

Note * The method is limited to a lower value on $\sigma_{\text{max}}$ compared to the other methods. In order to achieve higher values, the gripping section of the test specimen can be shotpeened.

Gripping method B

This method can only be used for gripping devices which distributes the clamping forces evenly.

The procedure shall be as follows:

- Determine the centre of the test specimen for instance by setting it up in a lathe by a three-jaw chuck and drilling a hole in the end, one at a time.
- Before the lamination the test section shall be protected with a strip of polypropylene.
- The lamination shall be made in a specially designed apparatus which continuously feed the glass fibre strip through the bath and around the rotating test specimen.
- The lamination shall be made over a length of at least 120 mm at each end with glass fibre strip and epoxy resin.
- Immediately after the lamination the ends of the test specimen shall be wound with a 50 mm wide strip of polypropylene in order to compress them during the hardening process of the epoxy.
- The laminated ends shall be hardened according to the directions from the manufacturer.

- The laminated ends shall be machined to fit the hydraulic grips.
- The protecting strips of polypropylene shall be removed after the test specimen has been mounted in the testing machine.

Gripping method C

This method can only be used for gripping devices which distributes the clamping force evenly.

The procedure shall be as follows:

- In a lathe reduce the diameter over the gripping length of the test specimen by about 1 mm.
- An aluminium tube with an inside diameter equal to the turned part diameter, and a wall thickness of 1 ... 2 mm shall be cut to a length equal to the turned part length and then halved longitudinally.
- Both the turned parts and the inside of the tube halves shall be sandblasted.
- The tube halves shall be glued on the turned parts.
- After the prescribed time of hardening a radius shall be turned between the aluminium tube and the test section as shown on Fig 3.

Gripping method D

This method is normally used for pre-stressing steel. The method consists of using two different sets of gripping devices or using a very long set of jaw faces in order to distribute the forces over a longer distance than normally. It is also advisable to use some sort of inlay in the first set of gripping devices on the longer jaw faces.

![Diagram](image-url)
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 such cases the cross-sectional area shall be determined according to one of the methods described in NORDTEST NT MECH 005.

5.5 Conditions of testing
5.5.1 Mounting of the test specimen
Each test specimen shall be mounted in the testing machine in such a manner that stresses at the test section other than those imposed by the applied load are avoided. Every effort should be made to prevent the occurrence of misalignment. The clamping force of grips should also be under control.

5.5.2 Loads
The test loads shall be monitored continuously in the early stage of the test and periodically thereafter to ensure that the desired force cycle is maintained.

5.5.3 Test frequency
Having particular regard to the heating of the test specimen, fatigue effects due to frequency are usually negligible up to 200 Hz. Above this frequency (and in some cases below) it will often be necessary to verify by tests that fatigue strength is insensitive to frequency.

5.5.4 Ratio of stress
The choice of stress ratio $R_s$ will depend on the type of information required from the test. The ratio of stress can either be set in tension, compression or tension-compression.

5.5.5 Number of cycles
The test is continued until the test piece fails or until a predetermined number of stress cycles has been exceeded, at least $2 \times 10^6$. The criterion of failure is either the occurrence of a visible fatigue crack or complete fracture. In particular applications other criteria, for example plastic deformation of the test specimen may be adopted.

5.5.6 Number of test specimens
If the fatigue test is performed only to verify the fatigue strength ($\sigma_u$) or the fatigue limit ($\sigma_D$) given in a product standard it will be sufficient with a small number of test specimens of the same type and diameter. If the fatigue test is performed to obtain a fuller information about the resistance of a reinforcing bar to fatigue so many test specimens should be tested that one could draw at least one curve in a so called $\sigma$-N-diagram (see Fig 4).
Mean regression curve: $N(\sigma_{\text{max}} - \sigma_{\text{min}})^{4.79} = 3.943 \cdot 10^{-7}$
Standard deviation: $s = 0.1198$
95% confidence interval for mean curve = 0.1981
Fatigue limit (horizontal line) fitted by eye

Material: Reinforcing bar, 16 mm, K600
Environment: Air, room temperature
Stress ratio, $R$: 0.05
Frequency: 15 Hz

Fig 4. Example of $\sigma$-$N$ diagram
6 TEST RESULTS
The results of fatigue tests are usually presented graphically, and the most common presentation is the $\sigma$-N (stress life) diagram, Fig 4. The dependent variable, fatigue life $N$ in cycles, is plotted on the abscissa, a logarithmic scale. The independent variable, maximum stress $\sigma_{\text{max}}$, stress range $\sigma_{\text{max}} - \sigma_{\text{min}}$ or stress amplitude $\sigma_a$ in MN/m$^2$ (MPa), is plotted on the ordinate, an arithmetic or logarithmic scale. A line is faired by eye through, or fitted by regression analysis, to the fatigue data.

The $\sigma$-N curve for certain materials shows a distinct change of slope in a given number of cycles such that the latter part of the curve is a horizontal line representing the fatigue limit.

Information to be presented for each fatigue test specimen should include the reason for test termination, either achievement of the failure criterion or that the predetermined number of cycles have been reached, and, if applicable, a description of the failure surface appearance and location of the crack origin.

7 TEST REPORT
The test report shall include the following information when 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 related information (date and person responsible for the sampling etc.)
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) Number of test specimens
m) Preparation of the test specimens
n) Conditioning of the test specimens, environmental data during the test (temperature, air pressure, relative humidity, etc)
o) Identification of the test equipment and instruments used
p) Any deviations from the test method
q) Test results (use SI units)
r) Inaccuracy or uncertainty of the test result
s) Conclusion
t) Date and signature