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Mechanical joining — Guidelines for fatigue testing of joints

Assemblage mécanique — Lignes directrices pour les essais de fatigue des assemblages

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 6, *Resistance welding and allied mechanical joining*.

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Introduction

This document gives recommendations for fatigue testing of test specimens with dimensional information for single- and multi-joint specimens for riveted, clinched and screwed mechanical joints. H-shaped, hat-shaped, double-disc and KS-2 type specimens are specified. This document is based on ISO 18592, the standard on the fatigue testing of resistance spot welds.

The fatigue tests specified in this document are conducted at room temperature, at constant load amplitudes and specified load ratios. For most of the specimens, the primary loads experienced by the joints are shear and peel loads. Some test specimens can be subjected to torsion or bending loads; the joints themselves experience non-uniform shear and peel loads.

Mechanical joining — Guidelines for fatigue testing of joints

1 Scope

This document gives recommendations for test specimens and procedures for performing constant load amplitude fatigue tests on single- and multi-joint sheet specimens in the thickness range from 0,5 mm to 6 mm at room temperature and a relative humidity of max. 80 %.

NOTE The thickness range for advanced high strength steels (AHSS) and ultra high strength steels (UHSS) is generally below 3,0 mm. Greater thicknesses apply for aluminium alloys, for example.

This document covers:

— testing of joints to evaluate materials;

— evaluation of the influence of joint type and joint size on the test results;

— evaluation of the influence of load type and load mode on the test results;

— testing of component-like specimens to evaluate their structural performance.

Depending on the specimen used, it is possible from the results to evaluate the fatigue behaviour of joints under shear-, peel-, normal-tension and combinations of loads and that of the tested specimen.

The results of fatigue testing obtained with component like specimens are suitable for deriving criteria for the selection of materials and thickness combinations for structures and components subjected to cyclic loading. This statement is especially relevant for results obtained with specimens with boundary conditions, i.e. a local stiffness, similar to that of the structure in question. The results of fatigue testing are suitable for direct application to a design only when the loading conditions in service and the stiffness of the design in the joint area are similar.

This document does not apply to civil engineering applications such as metal building and steel construction which are covered by other applicable standards.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
load
repeated load
F
applied force varying simply and periodically between constant maximum and minimum values

Note 1 to entry: Adapted from ISO 14324:2003, 3.12.

3.2
maximum load
F_{max}
highest algebraic value of the *repeated load* (3.1)

[SOURCE: ISO 14324:2003, 3.9]

3.3
minimum load
F_{min}
lowest algebraic value of the *repeated load* (3.1)

[SOURCE: ISO 14324:2003, 3.11]

3.4
load range
ΔF
difference between maximum and *minimum loads* (3.3)

$$\Delta F = F_{max} - F_{min}$$

[SOURCE: ISO 14324:2003, 3.8]

3.5
load amplitude
F_a
half of the *load range* (3.4)

$$F_a = 0{,}5\ \Delta F$$

[SOURCE: ISO 14324:2003, 3.6]

3.6
mean load
F_m
average of maximum and *minimum loads* (3.3)

$$F_m = 0{,}5\ (F_{max} + F_{min})$$

[SOURCE: ISO 14324:2003, 3.10]

3.7
load ratio
R
minimum load (3.3) divided by the *maximum load* (3.2)

$$R = \frac{F_{min}}{F_{max}}$$

[SOURCE: ISO 14324:2003, 3.7]

3.8
load type
primary shear or primary peel load

3.9
load mode
constant amplitude or variable amplitude loading

3.10
fatigue life
N_f
number of load cycles at which failure occurs, or before a failure criterion defined for the test is fulfilled

3.11
fatigue endurance
N_e
number of cycles at which it has been agreed to terminate the test even if failure does not occur

3.12
***F-N* diagram**
diagram obtained by plotting the *load amplitude* (3.5) [or *load range* (3.4), or *maximum load* (3.2)] on the ordinate and the number of load cycles [or *fatigue endurance* (3.11) if the test is terminated before failure] on the abscissa

Note 1 to entry: *F-N* diagram is also called *F-N* Wöhler diagram or load-amplitude/number of load cycles diagram.

Note 2 to entry: It is normal practice to use logarithmic scales on both axes.

Note 3 to entry: This type of diagram is generally used when testing mechanically joined or welded specimens because one compares the performance of the joint or the weld, but not the performance of the joints or welds based on their respective cross sections.

3.13
***S-N* diagram**

diagram obtained by plotting the stress amplitude (or stress range, or maximum stress) on the ordinate and the number of load cycles [or *fatigue endurance* (3.11) if the test is terminated before failure] on the abscissa

Note 1 to entry: *S-N* diagram is also called *S-N* Wöhler diagram or stress-amplitude/number of load cycles diagram.

Note 2 to entry: The *S-N* diagram is generally not suitable for specimens with spot shaped and mechanical joints because the stress is based on the cross-section of the joint or of the component.

Note 3 to entry: This type of diagram is generally used for comparing the performance of structures and component like specimens especially if the type of load distribution is undefined and/or non-uniform, e.g., closed section specimens subjected to 3-point bending or torsional loading.

3.14
endurance limit
maximum load (3.2) or *load range* (3.4) at which a test specimen can endure a specified number of load cycles without failing

3.15
fatigue limit
load amplitude (3.5) [or *load range* (3.4), or *maximum load* (3.2)] which the test specimen can be endure an infinite or specified number of load cycles without failing

3.16
displacement range
ΔL
change in the length of a specimen ($L_{max} - L_{min}$) between loads F_{max} and F_{min}

3.17
displacement amplitude
half of the *displacement range* (3.16) $\left(\frac{\Delta L}{2}\right)$

3.18
stiffness
C
load range (3.4) divided by the corresponding *displacement range* (3.16)

$$C = \frac{F_{\max} - F_{\min}}{\Delta L}$$

Note 1 to entry: The stiffness of a specimen represents a measure of its change in length under load. In the fatigue testing of specimens, the change in stiffness represents a loss in integrity of the specimen.

Note 2 to entry: Stiffness is also defined as load-displacement ratio.

3.19
initial stiffness
C_0
load displacement ratio at stable condition, i.e.

$$C_0 = \frac{F_{\max} - F_{\min}}{\Delta L_0}$$

Note 1 to entry: In cases in which a stable condition is not achieved, a *stiffness* (3.19) value calculated at either 10 s or at 500cycles after the start of the test, whichever occurs earlier is to be used as the initial stiffness.

Note 2 to entry: A stable condition is either one in which, for the first time during a test, the stiffness remains constant within a range of ±1,5 % for a period of 10 s or over 500 cycles, whichever occurs first or, the stiffness shows a continuous linear decrease over a period of 10 s or 500 cycles, whichever occurs earlier.

3.20
stiffness loss
C_L
reduction in *stiffness* (3.18) compared to the *initial stiffness* (3.19)

$$C_L = \frac{C_0 - C_N}{C_0}$$

3.21
relative stiffness
C_{rel}
stiffness (3.18) at N number of load cycles C_N divided by the *initial stiffness* (3.19) C_0:

$$C_{rel} = \frac{C_N}{C_0}$$

3.22
relative percentage stiffness loss
C_{Lrel}
decrease in *stiffness* (3.18) at N load cycles, compared to the *initial stiffness* (3.19), expressed as percentage

$$C_{Lrel} = \frac{C_0 - C_N}{C_0} \times 100$$

3.23
slippage load
F_{sl}
load at which slippage occurs during testing

Note 1 to entry: Slippage may be defined as a failure criterion.

3.24
slope of best fit at 50 % probability of fatigue life
k
gradient or slope of the line of best fit when the results of a fatigue test are plotted in a double logarithmic *S-N* or *F-N* or Wöhler diagram, determined via linear regression

Note 1 to entry: The probability of survival for different probabilities of survival, e.g. 5 %/95 % or 10 %/90 %, can also be calculated under the assumption that the scatter at each load level is identical.

4 Symbols and abbreviated terms

For the purposes of this document, the symbols presented in Table 1 apply.

Table 1 — Symbols and abbreviated terms

Symbol/abbreviated term	Definition
A	overlap
B	test specimen or coupon width
b_{i}	internal width of test coupon
C	stiffness
C_0	initial stiffness (stiffness at stable condition)
C_N	stiffness at N load cycles
C_{L}	stiffness loss
C_{rel}	relative stiffness
C_{Lrel}	relative stiffness loss in percent
d_{c}	diameter of central hole
d_{e}	diameter of pitch circle
E	pitch or distance between mechanical joints
F	load/repeated load
F_{a}	load amplitude
F_{m}	mean load
F_{max}	maximum load
F_{min}	minimum load
F_{p}	peel load
$F_{\mathrm{p,max}}$	maximum peel load
$F_{\mathrm{p,min}}$	minimum peel load
F_{pt}	peel load transverse to the joint line
F_{s}	shear load
$F_{\mathrm{s,max}}$	maximum shear load
$F_{\mathrm{s,min}}$	minimum shear load
F_{sl}	slippage load
F_{st}	shear load transverse to the joint line
H	outer height of hat-section
h_{i}	inner height
h_{o}	outer height
h_{H}	total height of H-specimen
h_{s}	height of side plate or side member
h_{L}	height of L member
h_{U}	height of U member

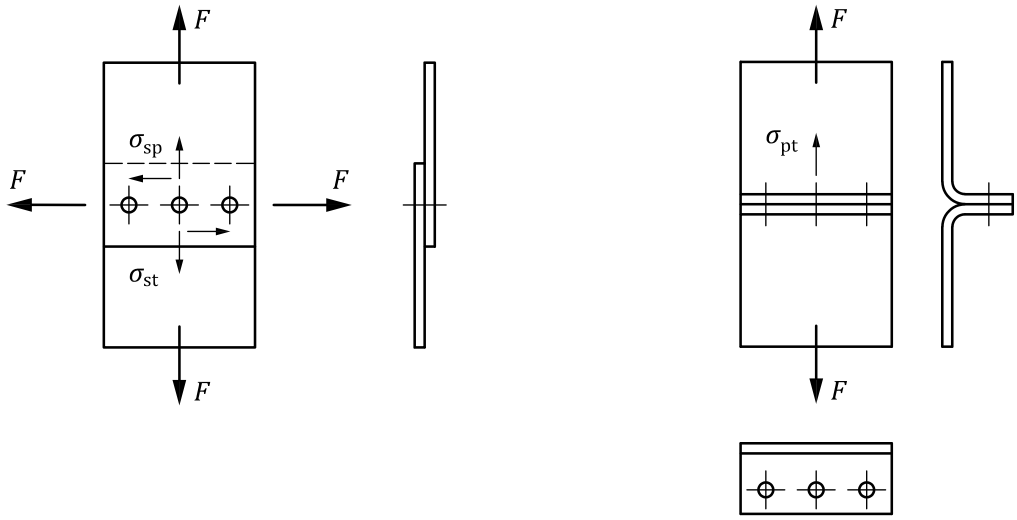
Table 1 *(continued)*

Symbol/abbreviated term	Definition
l_a	distance between clamps and overlap
l_c	length of clamped area
l_e	edge distance
l_g	specimen length between clamps
l_S	total length of specimen
l_t	length of test coupon
l_w	distance from wall
L	crosshead displacement
L_m	displacement at mean load F_m
L_{max}	displacement at max load F_{max}
L_{min}	displacement at min. load F_{min}
N	number of load cycles
N_f	number of load cycles at which failure occurs (fatigue life)
N_e	fatigue endurance
N_{AI}, N_{AII}	number of load cycles using absolute stiffness loss as failure criterion for the two different specimens
N_{RI}, N_{RII}	number of load cycles using relative (percentage) stiffness loss as failure criterion for the two different specimens
r_1	bend radius for sheet thickness t_1
r_2	bend radius for sheet thickness t_2
R	load ratio
τ	time
t	sheet thickness
ε_i	strain measured at a bridge position *i* on the calibration specimen
ε_m	average strain measured on the calibration specimen
σ_p	peel stress
σ_{pt}	peel stress transverse to the joint line
σ_s	shear stress
σ_{sp}	shear stress parallel to or in the axis of the joint line
σ_{st}	shear stress transverse to the joint line
ΔL	displacement range
ΔF	load range
ΔP	non-uniform loading
ΔP_i	degree of non-uniform loading at position *i*
ΔP_{max}	maximum value of non-uniform loading
AHS	advanced high strength (steel)
UHS	ultra high strength (steel)

5 Specimens

5.1 General

The specimens are designed to simulate, for joints in thin-walled structures, three basic types of loads in their primary forms, i.e. shear load (transverse to the joint line, shear load parallel to or in the axis of the joint line), and peel load, (see Figure 1). In addition, component like specimens e.g., hollow profiles as shown in Figure 10, Figure 11 and Figure 12 can be subjected to torsion and 3-point bending. With these specimens, the performance of the structure is evaluated, the joints themselves experiencing an undefined, non-uniform load distribution with a combination of shear and peel loads, the loads being highest in the middle of the specimens and lowest at the clamped ends.



a) Shear load (transverse to the joint line or shear load in the axis of the joint line)

b) Peel load

Figure 1 — Three basic joint load cases

NOTE 1 For true-to-life thin-walled structures, it can generally be assumed that joints are never subjected to any of the types of stresses listed above either singly or in a pure form. For lap joints, subjected to shear loads at least one type of shear stress and, due to the local deformation of the sheets caused by it, peel stresses are present. Even if the primary stress in a lap joint is pure shear, a peel stress component is generated, whose absolute value depends on the magnitude of the deformation caused by the shear stress in the joint. This deformation is a function of the bending moment, which depends on the sheet thicknesses involved, the magnitudes of the acting forces and the local stiffness. The stiffness itself is a function of the sheet thicknesses, Young's modulus of the material(s), the flange width, the overlap, the location of the joint on the flange, the bending radii, etc.

NOTE 2 The component type H-specimens were designed to be used with various joining methods and joining elements, e.g. spot welding, blind rivets, self-tapping and thread forming screws, self-piercing rivets, lock bolts, blind bolts, clinching, friction stir spot welding, laser welding and gas metal arc welding, and thus allow a comparison of the load-carrying properties of joints made with different methods.

Due to the necessity of larger bending radii than specified in the corresponding tables, space requirements for tool accessibility or size of the joining elements, etc., it can be necessary to modify the flange width, overlap or the edge distance. Despite any such modifications, it should be ensured that the joints are tested under optimum boundary conditions.

For single– and double-hat specimens subjected to torsion and 3-point bending loads, the joints themselves are subjected to complex loads, whereby the ratios of the load types and the load distribution are non-uniform and undefined. Furthermore, the ratios of the three basic types of loads listed in the first paragraph of this sub-clause are a function of the load amplitude, the clamping conditions, and the sheet material- and thickness combinations.

The quality, value and usefulness of the results of fatigue tests depend to a large extent on the degree of care taken in the fabrication of the specimens, their testing, the acquisition and evaluation of test data, and the comprehensiveness of the documentation.

5.2 Test specimen materials

The materials used for the fabrication of the specimens should be the same as those used for the products or components. The materials should, if possible, be taken from the same material lot, and the rolling direction should be identical for all coupons. Material specification, including any heat treatment and forming operation, type, thickness and location of coating(s), sheet thickness, surface condition and mechanical properties should be checked before the actual tests, and documented.

Storage of coupon material should be such that corrosion and other surface damage due to environmental conditions and mechanical abuse is avoided.

5.3 Types of test specimens

Several types of test specimens are currently used in fatigue tests, see Figure 4 to Figure 14. The aim of this document is to help the user to select specimens suitable for the task in hand.

5.4 Selection of suitable specimens

The selection of a suitable specimen for fatigue testing depends on the planned usage of the test results. A basic requirement of the specimen is that it should allow the relevant load type, load mode, load range and load ratio to be simulated. If the results are to be used for design purposes, then it is important to employ specimens with which a similar load distribution can be realized. Further, the stiffness of the specimen in the joint area should be similar to that of the component under consideration.

The local stiffness of the joint area in the component in question should be considered in addition to the primary loading condition of the joints. The fatigue life of joints is influenced decisively by the peel load and not by the shear load. For example, if joints could be subjected to identical amplitudes of shear and peel loads, their lives would differ by a factor of ~10^4, the life of the joints under shear loading being longer.

As can be seen in Figure 2, mechanical joints would never fail under a shear load at which identical joints under a peel load have a life of about 1 000 cycles. As stated above, the magnitude of the peel component depends on the shear load and the local stiffness of the specimen.

The validity of the statements made in the last two paragraphs depends, as can easily be understood, on the positions and on the slopes of the *F*-*N* (Wöhler) diagrams, see Figure 2.

Especially in the case of single joint tensile shear specimens, Figure 4, the local stiffness is much lower than is usual in real structures. Therefore, the bending moment is comparatively large, i.e., the peel/shear ratio is comparatively large, resulting in a significantly shorter fatigue life as compared to identical joints tested on H-specimens.

In addition, some materials are particularly sensitive to peel stress in the as-joined condition so that results obtained with specimens with a low stiffness can be misleading with regard to the behaviour of such joints in structures.

The H-specimens allow the investigation of almost all parameters including different stress ratios and stress distributions. They require special clamps for testing and their fabrication is relatively complicated. However, under uniform loading, it is possible with these specimens to obtain results with a high significance with 5 to 7 specimens.

When selecting a specimen, some of the main considerations should be:

a) the simulation of the type of loading and load ratio in the component under consideration;

b) simulation of design parameters such as stiffness, pitch, edge distance and flange width;

c) simulation of the stress distribution in the component;

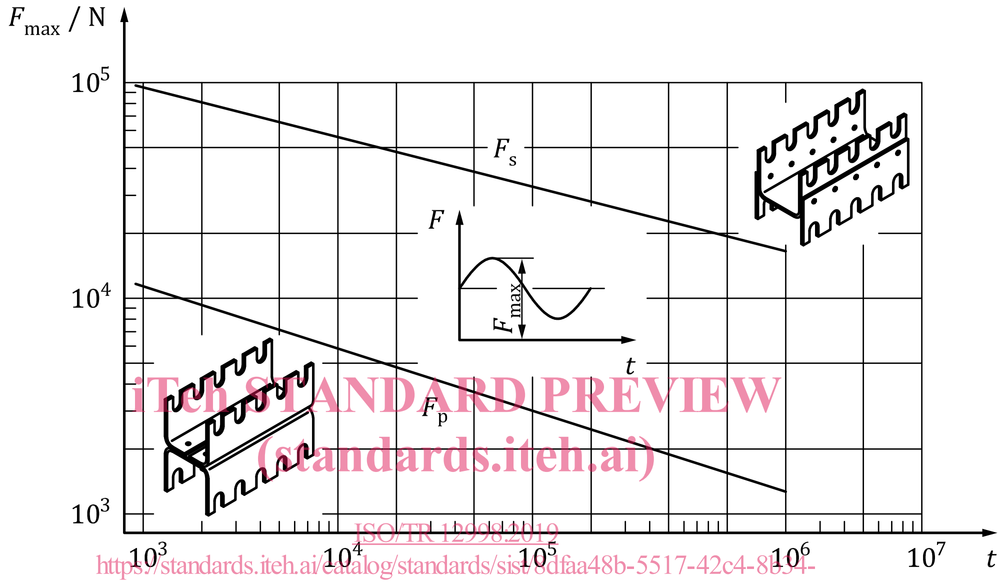
d) effort and time required for fabrication and testing;

e) number of specimens required to obtain statistically significant results.

NOTE 1 The results obtained with specimens with a low stiffness generally bias mechanical joints, especially in the case of high strength steels.

NOTE 2 The time required for specimen fabrication is only a fraction of that required for specimen testing. For example, once the required jigs are available, and the coupons have been bent and the holes drilled or punched, the fabrication of an H-specimen does not require more than a few minutes. This is not much longer than the time required for fabricating a single joint specimen. The testing times for a single joint specimen and an H- specimen are more or less identical. Depending on the type of testing machine being used, testing time can be between a few minutes for low cycle tests and up to a day or several days for high cycle tests. The clamping procedure for an H-specimen takes between 2,5 minutes to 5 minutes, depending on whether bolts or hydraulic clamps are being used. The testing time required for obtaining results with the same statistical significance in the case of single joint specimens is about 10 times longer than that required for H-specimens. This is due to the fact, that with an H-specimen, 10 joints are tested under identical loading conditions at the same time. The implications of these facts in terms of time and money savings are often neglected when selecting a suitable specimen.

An example of a table for the selection of a suitable specimen is shown in Table 2.



NOTE 3 See Clause 4.

Figure 2 — *F-N* diagrams (Wöhler diagrams) of H-specimens subjected to shear and peel loading, load ratio, *R* = 0,1 – schematic

Table 2 — Selection of a suitable specimen based on the aim of the test

Aim of test	Shape of test specimen and suitability rating[a]				
	Single or multi-joint overlap specimen	Flat multi-joint specimen (tensile shear or peel)	H-specimen	Single hat or double-hat specimen	KS-2 specimen
Evaluation of materials	3	2	1	1 or 4	1
Evaluation of structures	4	2	1	1	1
Influence of joint size	3	2	1	1 or 3	1