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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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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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

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

Any feedback, question or request for official interpretation related to any aspect of this document should be directed to the Secretariat of ISO/TC 44/SC 6 via your national standards body. A complete listing of these bodies can be found at www.iso.org/members.html. Official interpretations, where they exist, are available from this page: https://committee.iso.org/sites/tc44/home/interpretation.html.

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 re*peated 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

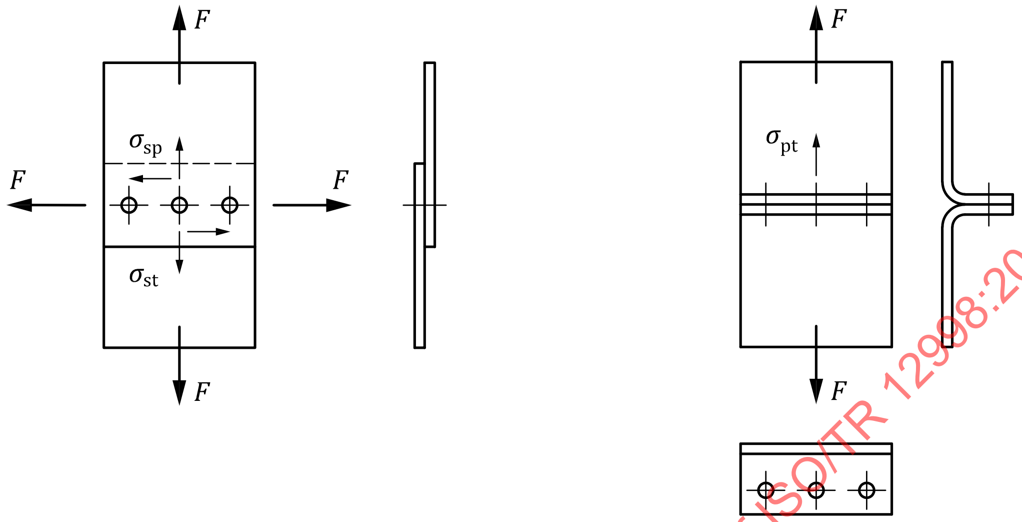
Table 1 *(continued)*

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;

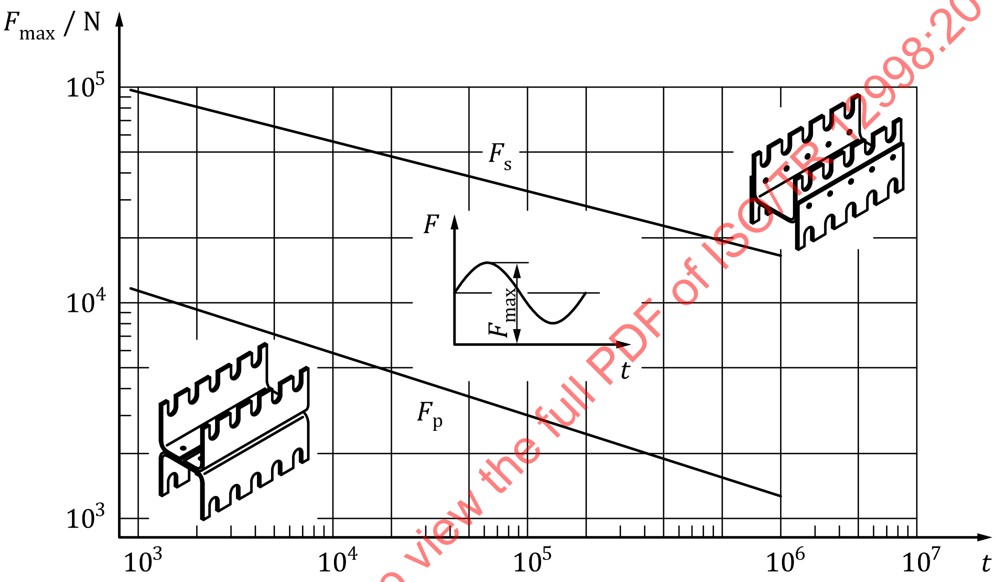
d) effort and time required for fabrication and testing;

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

Table 2 *(continued)*

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
Influence of load type	2	2	1	4	2
Influence of test environment	3	2	1	3	1

[a] The ratings 1 to 3 and 1 to 4 denote that the suitability of the specimen depends on the testing jig used. The higher rating is only possible if a defined, uniform loading of the joints is possible, e.g. with 4-point bending. This is very rarely the case, because such jigs are difficult to design.

Suitability	Rating
Very good	1
Good	2
Fair	3
Poor	4

The statistical significance of test results is influenced by their scatter. The larger the number of joints tested under uniform loading in a single specimen, the smaller is the scatter. Therefore, in order to obtain results with the same degree of significance, the number of specimens to be tested with two joints, for example, is five times greater than H- or double disc specimens with 10 joints. Furthermore, the stiffness of flat specimens is appreciably lower than that of components, so that the results obtained with these specimens are generally misleading. In addition, some specimens cannot be subjected to or tested under compressive loads or negative load ratios, R, e.g. the two flat specimens made with thin aluminium sheets and one or two mechanical joints.

5.5 Test specimen fabrication

5.5.1 Coupons for specimen fabrication

The sheet material for the coupons may be in the sheared condition, but all burrs should be removed. Unintentional deformation, like bending or distortion of the coupons, and damage to the surface should be avoided. Test specimens made using such coupons may have an adverse effect on the test results and increase scatter. The dimensions of the coupons for the different specimens are given in Table 3 to Table 9 or in the corresponding figures. In cases where specimen components require bending, the dimensions will be influenced by the bend radius.

The sheet material for the specimens should be stored such that no damage or changes to the surface can occur, e.g. through condensation, humidity, chemical reactions, etc.

If the design under consideration uses extrusions or cast material, then the specimens should also be made using extruded profiles or cast material, e.g. aluminium and magnesium alloys as required by the design.

5.5.2 Bending and forming

The bending of the coupons for e.g. for making peel and H-specimens should be performed in a press brake to the required bend angle and radius. Ideally, the inner radius of the bent part should be 2 t (t = sheet thickness). If the material does not allow this radius, it may be bent to a radius larger than 2 t, but not greater than the maximum value indicated in Table 5 to Table 7. Once the inner radius has been determined, it should be maintained for all test specimens in the same test series.

The components of the double disc specimen require either the use of drawing- or deep-drawing tools or special manufacturing technologies such as casting for their fabrication. Press forming tools, e.g. deep-drawing tools, should not be used for other than the double disc specimens, because the large number of process parameters, e.g. clamping force, blank holder geometry, quantity and properties of lubricant, and surface roughness of tools, can influence the degree of work-hardening, sheet thickness and surface conditions, and thus the properties of the specimens, making a comparison of the results difficult or even impossible.

Generally, for AHS and UHS steels, much larger bend and drawing radii are necessary. In such cases, it can be necessary to modify the flange width, the edge distance and the location of the joints accordingly.

5.5.3 Joining

Suitable jigs should be used for positioning the coupons during joining and ensuring a precise location of the joints and uniform load distribution during testing.

Specific dimensions of specimens e.g. flange width and inner width of the KS-2 specimens should be modified in accordance with the space requirements for tool accessibility and larger dimensions of joints and joining elements, especially in the case of AHS and UHS steels and larger wall thicknesses.

The joining sequence for all specimens should be from the middle of the specimen towards the edge, see Figure 3. The joining sequence for the different multi-joint specimens should be such that enveloping is avoided. The size or diameter of all joints should conform to the specifications. If necessary, modify the joining force or displacement to compensate for the effect of work hardening and sheet thickness changes. In some cases, it can be necessary to use modified tools (clinching) or modified joining elements, e.g. self-piercing rivets.

The equipment and all parameters used for the fabrication of the specimens should be documented in the test report (see ISO 15609-5:2004, Annex A).

If mechanical joining is used in combination with an adhesive, the name and type of adhesive, information on the surface pre-treatment, curing temperature, etc. should be included in the test report.

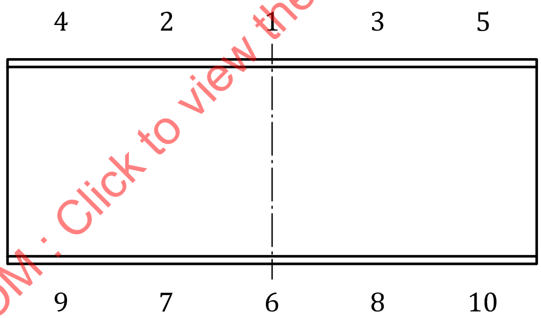


Figure 3 — Joining sequence for H-specimens

5.5.4 Tolerances

The accurate fabrication of the test specimens is of great importance, as improper methods of preparation can greatly bias the test results. More specifically, the tolerances should not exceed the values given in the tables for the respective specimens. For the hat and the double disc specimens the flange angle should be 90° ± 0,5°.

5.5.5 Storage

Test specimens susceptible to corrosion under normal storage conditions, e.g. in air at room temperature, should be protected accordingly, preferably by storage in an inert medium. The test specimen should be removed from the storage medium shortly before testing.

5.5.6 Inspection

All test specimens should be inspected before testing. Special attention should be paid to the geometry of the specimens, i.e. width and flange angles and to the joints. Gauges are recommended for the overall check of the dimensions.

5.6 Test specimen geometry

5.6.1 General

The geometry of the specimens, and the location, pitch and size of the mechanical joints, should be modified such that design and manufacturing requirements can be taken into consideration. For example, pitch, joint diameter/size and orientation, flange width, and the location of the joint on the flange may be modified as required. Suitable jigs should be used for positioning the coupons during joining and ensuring a precise location of the joints. Specific dimensions of specimens e.g. flange width and inner width of the KS-2 specimens should be modified in accordance with the space requirements for tool accessibility and larger dimensions of joints and joining elements, especially in the case of AHS and UHS steels and larger wall thicknesses.

The geometry and the dimensions of the different standard specimens are given in the corresponding figures and tables, below. Note that as stated under 5.1, specimen dimensions should be modified such that the joints are able to perform under optimum boundary conditions.

5.6.2 Specimen geometry of tensile shear and peel specimens

The specimens shown in Figure 4 and Figure 5 generally have a stiffness which generally is much lower than that of real structures. The usability of results obtained using such specimens is thus limited, see also 5.1 and 5.4.

The flat specimen with two joints, Figure 5 offers no real advantage as compared to the specimen in accordance with ISO 14273:2016, Figure 4, but is more difficult to manufacture and to test, requiring special grips for the wider versions.

The multi-joint tensile-shear and peel specimens shown in Figure 6 and Figure 7 are stiffer and offer a number of advantages over the single or two joint specimens in Figure 4 and Figure 5, allowing the influence of parameters such as pitch, overlap and uniform and non-uniform stress distribution to be investigated. These specimens require the use of the same clamps as the H-specimens shown in Annex C. It is however to be noted, that because of their higher stiffness, tests with H-specimens will, in absolute terms, generally deliver superior, more practice relevant results.

The geometries and dimensions of the different specimens are shown in the corresponding figures and tables.

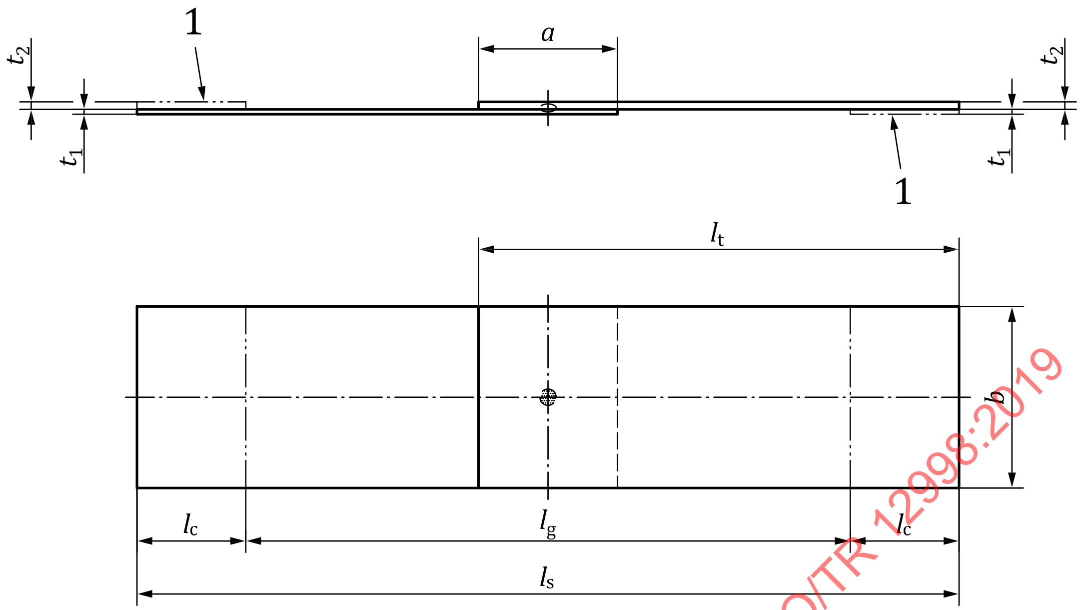
The bend radius should be in accordance with 5.5.2 but can need to be modified, e.g. in the case of AHS UHS steels and other materials with poor formability, and should be equal to or smaller than the indicated maximum values. If larger radii are necessary, then modifications to the edge distance, overlap and other dimensions of the specimens can be required.

The geometries and dimensions of tensile shear test specimens are given in Figure 4 to Figure 6 and Tables 3, 4 and 6. Figure 4 and Table 3 are applicable for single joint test specimens, Figure 5 and Table 4 for two joint test specimens and Figure 6 and Table 6 are for multi-joint tensile shear test specimens.

Figure 7 and Table 5 show the geometries and dimensions of multi-joint and H-peel specimens.

Figure 8 and Figure 9 and Table 5 and Table 6 show the geometries and dimensions of H- specimens.

Figure 8 and Table 6 are applicable for H-shear specimens, Figure 9 and Table 5 are for H-peel specimens.



Key

1	shim plates	l_g	specimen length between clamps
a	overlap	l_s	total length of specimen
b	test specimen and coupon width	l_t	coupon length
l_c	length of clamped area	t_1, t_2	thickness of the coupons

NOTE Shim plates are used to avoid misalignment when clamping the test specimen.

NOTE For specimens with sheets with unequal thicknesses, t_1, t_2, the dimensions given in Table 2 correspond to those specified for the thinner sheet.

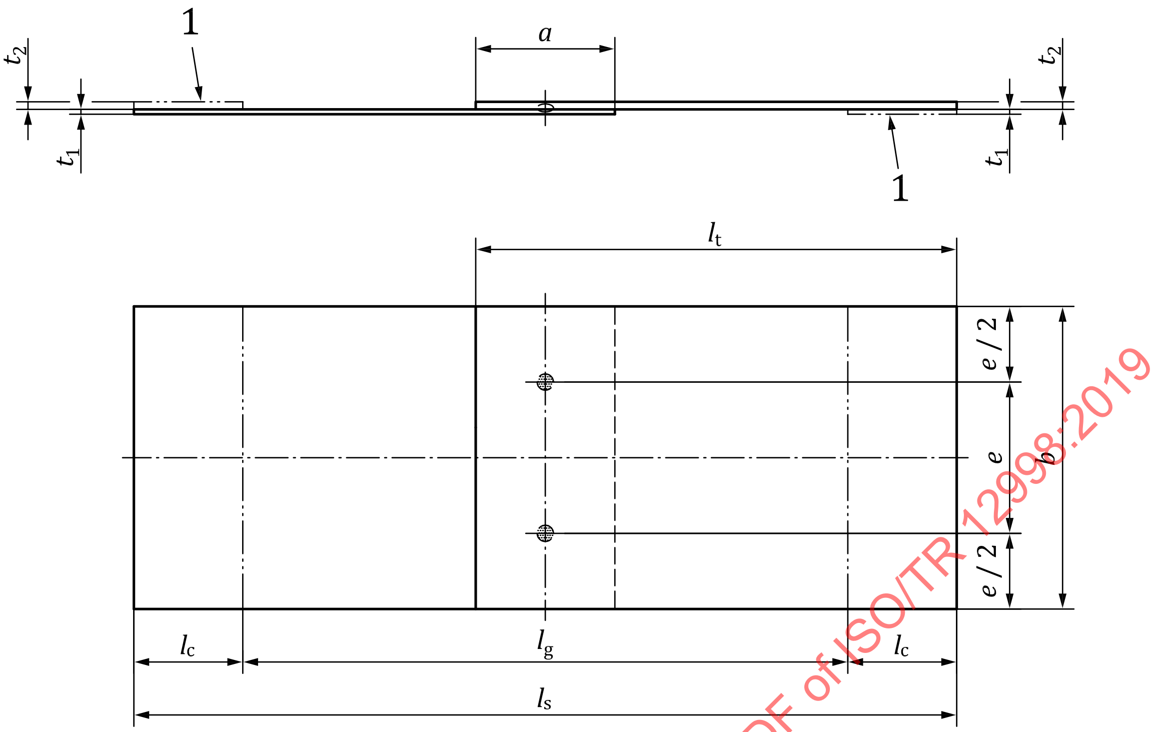
Figure 4 — Single joint tensile shear specimen

Table 3 — Dimensions of single joint tensile shear specimens

Dimensions in millimetres

Sheet thicknesses t_1, t_2	**Width** *B*	**Overlap** *a*	**Total length of specimen**[a] l_s	**Specimen length between clamps** l_g	**Length of single coupon**[a] l_t
$0,5 \leq t \leq 1,5$	45 ± 0,5	35	≥250	160	≥142,5
$1,5 < t \leq 3,0$	60 ± 0,5	46	≥320	200	≥182,5
$3,0 < t \leq 6,0$	90 ± 0,8	60	≥420	240	≥240

[a] These dimensions are applicable for older test machines with mechanical clamps. Under this assumption, the length of the clamped area l_c should be greater than the specimen width. For modern machines, in particular those with hydraulic clamps, the length of the clamped area as well as l_t and l_s may be reduced correspondingly.



Key

1 shim plates

a overlap

b test specimen and coupon width

e pitch

l_c length of clamped area

l_g specimen length between clamps

l_s total length of specimen

l_t coupon length

t_1, t_2 thickness of the coupons

NOTE For specimens with coupons with unequal thicknesses, t_1, t_2, the dimensions given in Table 3 correspond to those specified for the thinner sheet.

Figure 5 — Tensile shear specimen with two mechanical joints

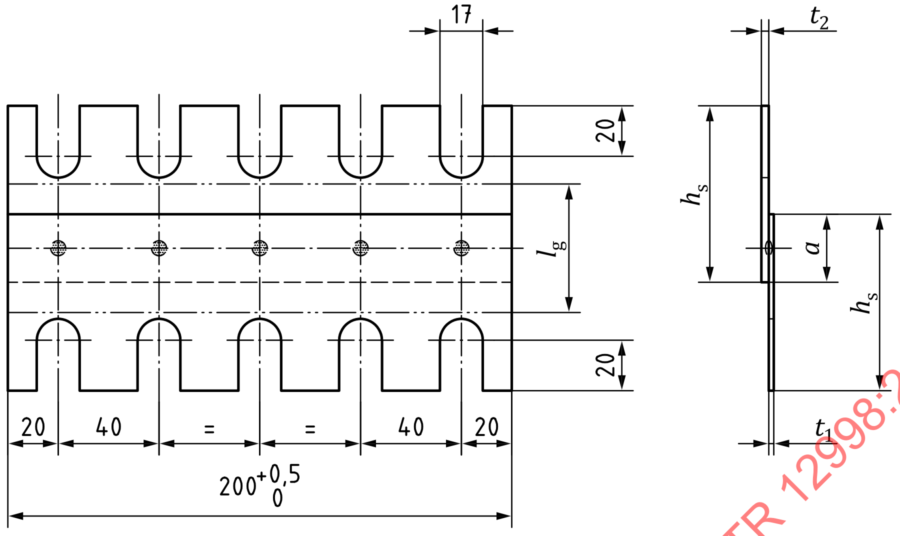
Table 4 — Dimensions of tensile shear specimens with two mechanical joints

Dimensions in millimetres

Sheet thickness t_1, t_2	Width b	Overlap a	Length of single coupon l_t[a]	Total length of specimen l_s[a]	Specimen length between clamps l_g	Pitch e
$0,5 \le t \le 1,5$	70	35	≥167,5	≥300	160	35
$1,5 < t \le 3,0$	100	45	≥222,5	≥400	200	50
$3,0 < t \le 6,0$	≥100	60	≥250	≥440	240	50

[a] These dimensions are applicable for older test machines with mechanical clamps. Under this assumption, the length of the clamped area l_c should be greater than the specimen width. For modern machines, in particular those with hydraulic clamps, the length of the clamped area, as well as l_t and l_S, can be reduced correspondingly.

Dimensions in millimetres

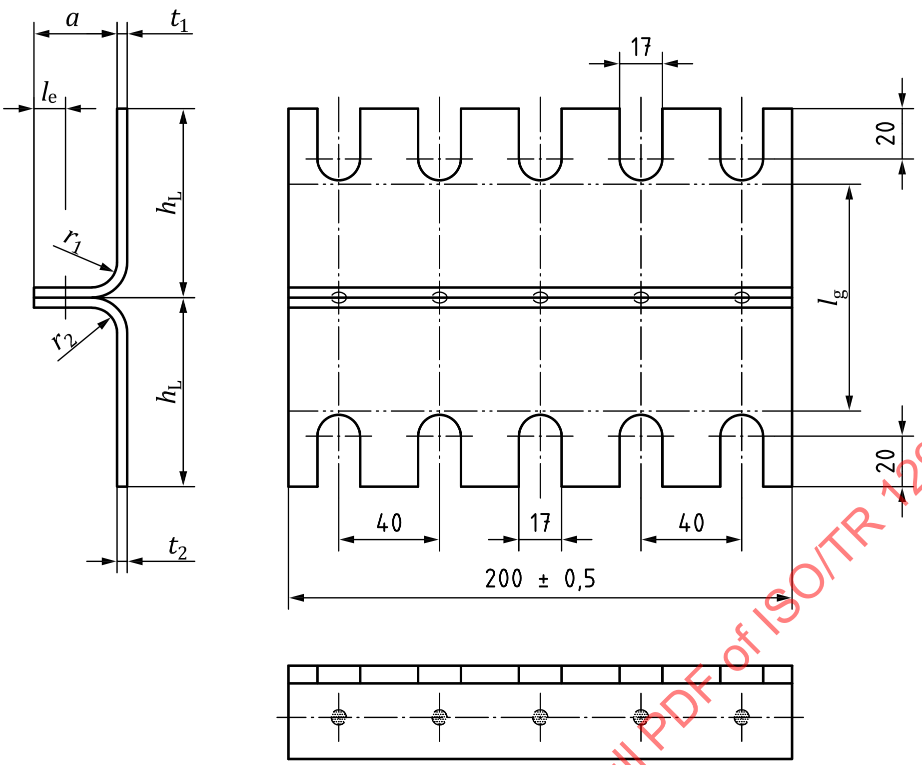


Key

a	overlap, see Table 6
h_s	height of side plate or side member = $a + l_a + 38$
l_g	specimen length between clamps= $a + 2\ l_a$
l_a	distance between overlap and clamp
t_1, t_2	thicknesses of the coupons

Figure 6 — Flat multi-joint tensile shear specimen

Dimensions in millimetres



Key

a	overlap
h_L	height of L member = (t_1 or t_2) + (r_1 or r_2) + 40
l_g	specimen length between clamps = $t_1 + t_2 + r_1 + r_2 + 4$
r_1, r_2	bend radius for sheet thickness t_1, t_2
t_1, t_2	thicknesses of the coupons

Figure 7 — "Flat" multi-joint peel specimen

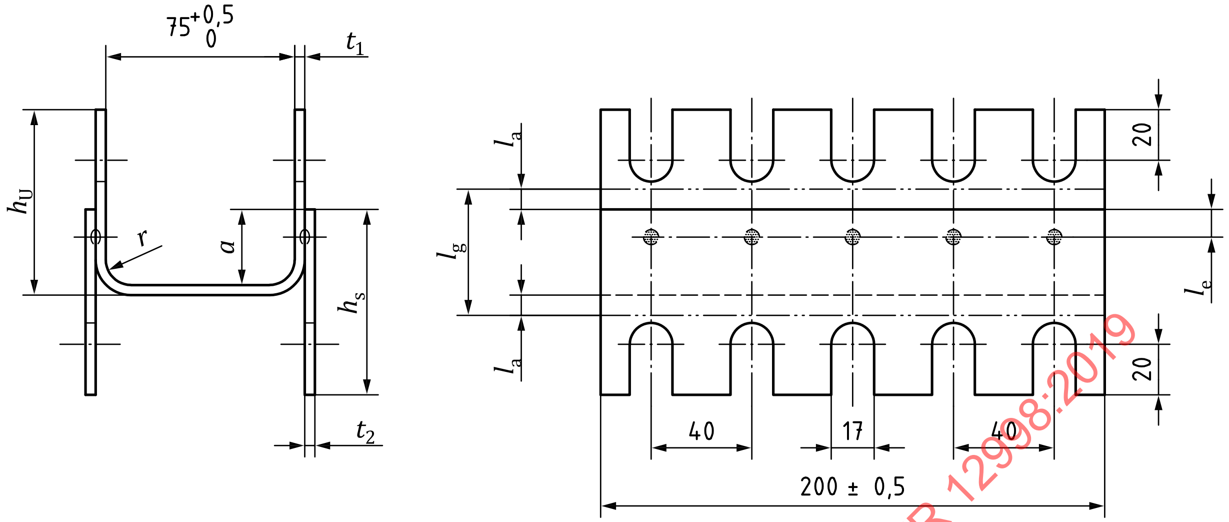
Table 5 — Dimensions of "Flat" multi-joint peel specimens and H-peel specimens

Dimensions in millimetres

Smallest sheet thickness t_1 or t_2	**Overlap** a	**Edge distance** l_e	**Bend radius** r_1 or r_2[a]
$t \leq 1$	16	7	$2 < r < 3$
$1 < t \leq 1{,}5$	18	7,5	$3 < r < 4{,}5$
$1{,}5 < t \leq 2$	21	8,5	$4 < r < 6$
$2 < t \leq 3$	27	11	$6 < r < 9$
$3 < t \leq 4$	34	14	$8 < r < 12$
$4 < t \leq 5$	39	15	$10 < r < 15$

[a] The bend radius for AHS and UHS steels and thicker gauges of other materials can need to be increased. In this case, modifications of overlap, edge distance and other dimensions can be necessary.

Dimensions in millimetres



Key

a overlap = 12 mm

l_a distance between clamps and overlap

l_g specimen length between clamps = $(2\ l_a + a + t_1)$

h_S height of side plate or side member = $38 + a + l_a + t_1$

h_U height of U member = $38 + l_a + a + t_1$

r bend radius

t_1, t_2 thickness of the coupons

Figure 8 — H-Shear specimen

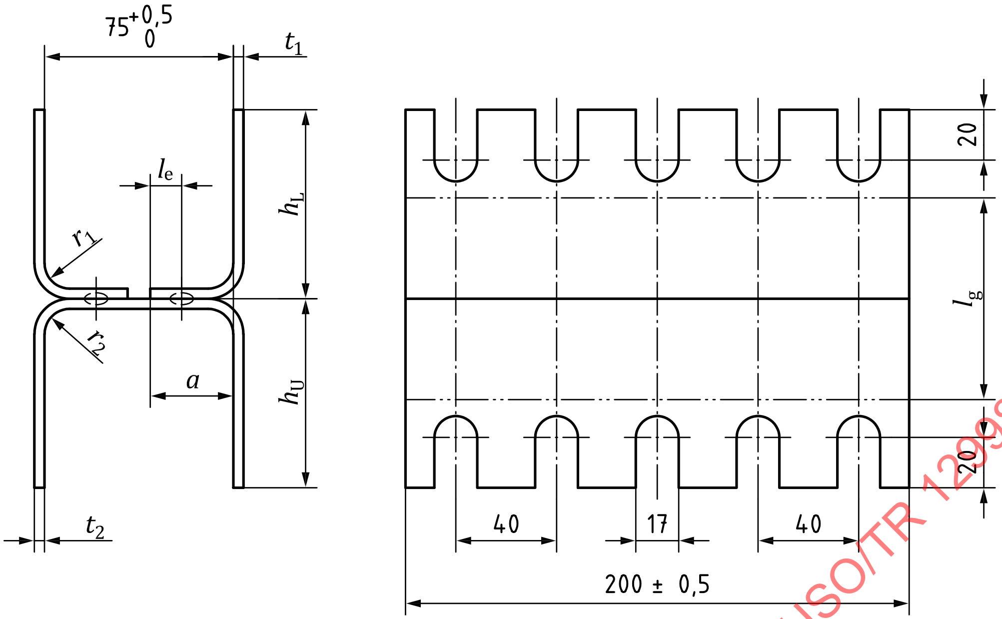
Table 6 — Dimensions of H-shear specimens

Dimensions in millimetres

Smallest sheet thickness t_1 or t_2	Distance between clamp and overlap l_a	Overlap a	Edge distance l_e	Specimen length between clamps l_g	Bend radius r[a]
$t \leq 1$	12	16	7	$40 + t_1$	$2 < r < 3$
$1 < t \leq 1{,}5$	12	18	7,5	$42 + t_1$	$3 < r < 4{,}5$
$1{,}5 < t \leq 2$	12	21	8,5	$45 + t_1$	$4 < r < 6$
$2 < t \leq 3$	12	27	11	$51 + t_1$	$6 < r < 9$
$3 < t \leq 4$	12	34	14	$58 + t_1$	$8 < r < 12$
$4 < t \leq 5$	12	39	15	$63 + t_1$	$10 < r < 15$

[a] The bend radius for AHS and UHS steels and thicker gauges of other materials can need to be increased. In this case, modifications of overlap, edge and other dimensions can be necessary.

Dimensions in millimetres



Key

a	overlap
h_L	height of L member = t_1+ r_1 + 41
h_U	height of U member = t_2+ r_2 + 41
l_e	edge distance
l_g	specimen length between clamps = t_1 + t_2 + r_1 + r_2 + 6
r_1, r_2	bend radius for sheet thickness t_1, t_2

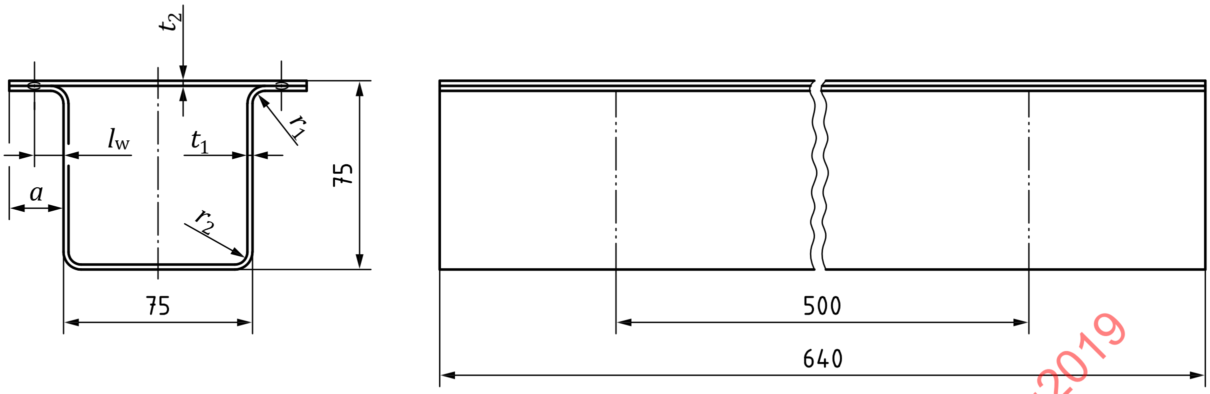
Figure 9 — H-peel specimen

5.6.3 Geometry of the hat and other closed section specimens

The hat specimens allow, under 3-point bending or torsion, the investigation of the structural behaviour of the specimens under different types of loading. An investigation of the load-carrying behaviour of the joints is not possible because these are subjected to undefined, non-uniform loads. The specimens are relatively difficult to fabricate and to test. The difficulty in fabrication increases with the number of bends and the length of the specimen. Under 4-point bending, these specimens allow the investigation of the load-carrying behaviour of the joints in the axis of the joint line.

Figure 10, Figure 11 and Table 7 show the geometries and dimensions of single-hat and double-hat specimens.

Dimensions in millimetres

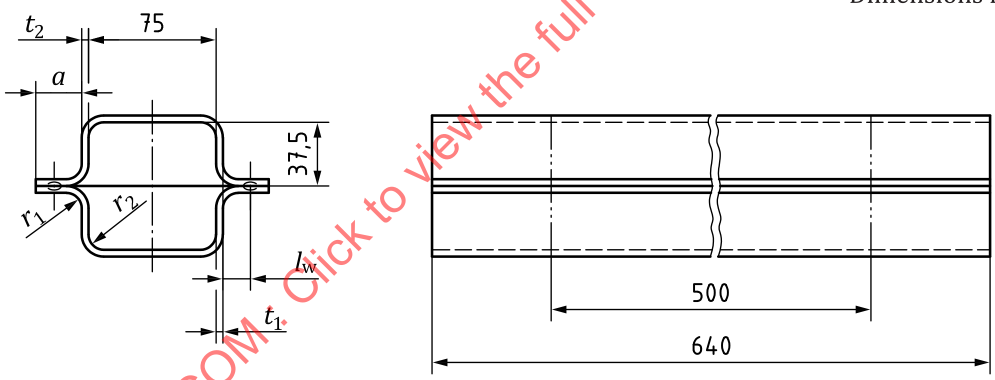


Key

a	overlap
l_w	distance from wall
r_1, r_2	bend radius for sheet thickness t_1, t_2
t_1, t_2	thickness of the coupons

Figure 10 — Single-hat specimen

Dimensions in millimetres



Key

a	overlap
l_w	distance from wall
r_1, r_2	bend radius for sheet thickness t_1, t_2
t_1, t_2	thickness of the coupons

Figure 11 — Double hat specimen

Table 7 — Dimensions of single-hat and double-hat specimens

Dimensions in millimetres

Smallest sheet thickness t_1 or t_2	Distance from wall l_w	Overlap A	Bend radius r_1 or r_2[a]
$t \leq 1$	8	16	$2 < r < 4$
$1 < t \leq 1{,}5$	9	18	$3 < r < 4{,}5$
$1{,}5 < t \leq 2$	11	21,5	$4 < r < 6$
$2 < t \leq 2{,}5$	12,5	25	$5 < r < 7$
$2{,}5 < t \leq 3$	13,5	27	$6 < r < 8$
$3 < t \leq 4$	14,5	34	$8 < r < 10$

NOTE There are 10 joints on each side, pitch 50.

[a] The bend radius for AHS and UHS steels and thicker gauges of some other materials can need to be increased. In this case, modifications of overlap, edge distance and other dimensions can be necessary

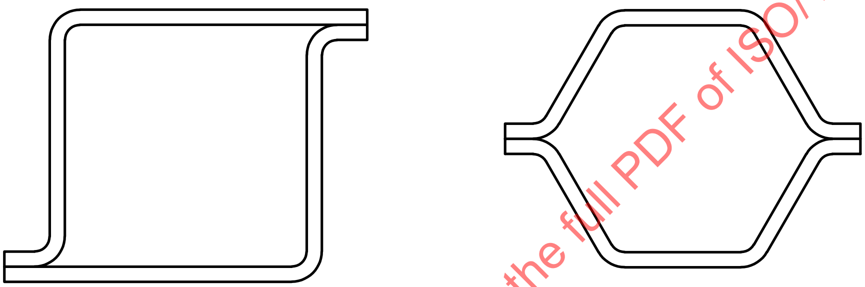
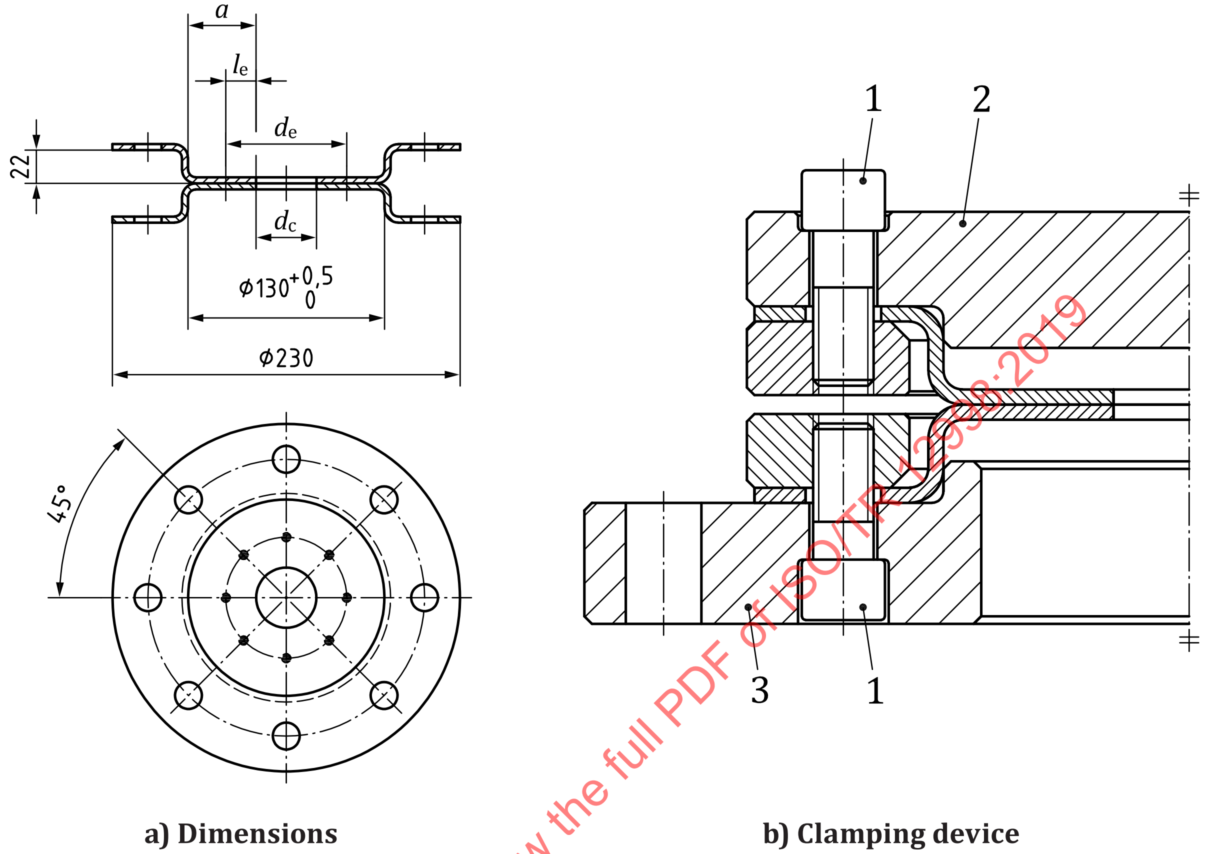


Figure 12 — Examples of various closed sections

Dimensions in millimetres



Key

a overlap

d_c diameter of central hole

d_e diameter of hole circle

l_e edge distance

1 clamping bolts

2 upper clamping plate

3 base clamping plate

Figure 13 — Double disc peel and shear specimens

Table 8 — Dimensions of double disc peel and shear specimens

Dimensions in millimetres

Smallest sheet thickness t_1 or t_2	**Overlap** *a*	**Edge distance** l_e	**Radius** r_1 or r_2[a]
$t \leq 1$	16	7	$2 < r < 3$
$1 < t \leq 1{,}5$	18	7,5	$3 < r < 4{,}5$
$1{,}5 < t \leq 2$	21	8,5	$4 < r < 6$
$2 < t \leq 3$	27	11	$6 < r < 9$

[a] The deep drawing radius for UHS and AHS steels and thicker gauges of some other materials can need to be increased. In this case, modifications of overlap, edge distance and other dimensions can be necessary.

5.6.4 Double disc and KS-2 specimen

The geometry and dimensions of the double disc specimen are given in Figure 13 and Table 8. These are valid for all thicknesses up to 3,0 mm. The number of joints should be distributed uniformly over the circumference of the pitch circle, resulting in a uniform pitch. The diameter of the central hole depends on the sheet thickness and should be (130 – 2a) mm. The greatest thickness for these specimens should be limited to 3 mm. The deep drawing radii depend on the thickness and forming properties of the material and should conform to the data given for the H-specimens. Larger radii can be necessary for AHS and UHS steels. Geometric modifications can be necessary in this case.

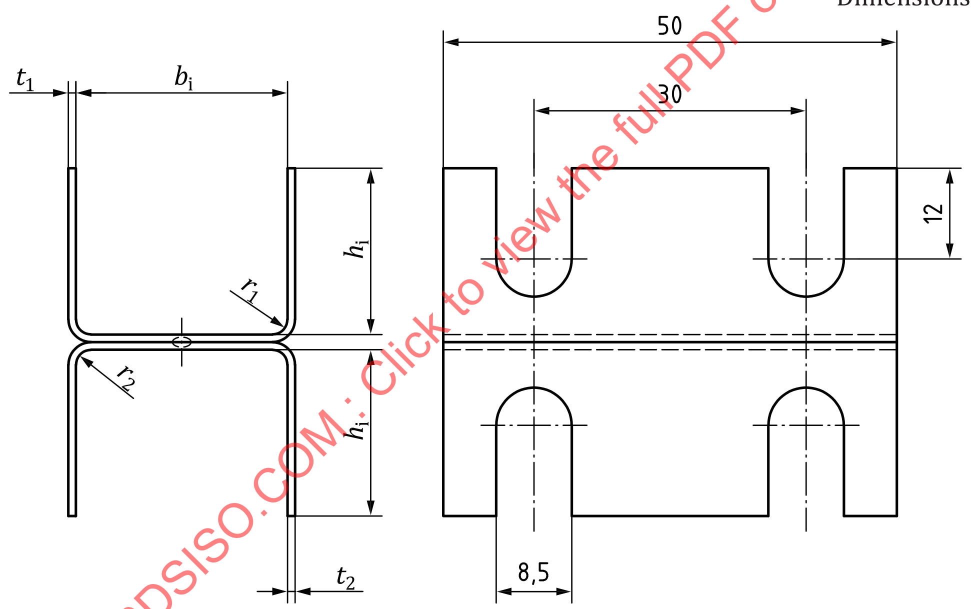
The fabrication of the double disc specimen requires special deep drawing tools for each sheet thickness.

Figure 14 and Table 9 show the geometries and dimensions of KS-2 test specimens. Note that the bend radius should be in accordance with 5.5.2 but can need to be modified in the case of AHS and UHS steels, and should be equal to or smaller than the maximum values given in Table 9.

The maximum thickness is limited to 5,0 mm.

The KS-2 specimen and the double disc specimen are the only ones which allow the simulation of defined complex loads. Their testing requires special clamps, and for the double disc specimen, also a tensile-cum-torsion testing machine.

Dimensions in millimetres



Key

b_i inner width of U-member

h_i inner height of "U-members" = (r_1 or r_2) + 26

r_1, r_2 bend radius for sheet thickness t_1, t_2

t_1, t_2 thickness of the coupons

Figure 14 — KS-2 specimens

Table 9 — Dimensions of KS-2 specimens

Dimensions in millimetres

Sheet thickness t_1, t_2	Minimum bend radius $r_{i,min}$	Maximum bend radius $r_{i,max}$[a]	Inner width b_i
0,8 < t ≤ 1,5	2	45	$22^{+0,5}_{0}$
1,5 < t ≤ 2,5	4	8	$26^{+0,5}_{0}$
2,5 < t ≤ 3,5	6	11	$30^{+0,5}_{0}$
3,5 < t ≤ 4,0	8	12	$34^{+0,5}_{0}$
4,0 < t ≤ 5,0	10	15	$36^{+0,5}_{0}$

[a] The bend radius for AHS and UHS steels and thicker gauges of some other materials can need to be increased Depending on the bending radius and the geometry of the joining element, modifications of other dimensions, e.g. the inner width, can also be necessary.

6 Specimen clamps and alignment

6.1 General

Special clamps are necessary for each type of specimen to ensure that the required stress distribution in the specimen is realized. For H-specimens, the standard clamps ensure that all joints are subjected to a uniform stress distribution. For tests in which a defined non-uniform stress distribution is required, either the clamps or the specimens or both require modification. The location of the joints and the pitch remain unchanged.

The following applies, by way of example, for the H-specimens. Similar instructions are applicable for the KS-2 specimens, the hat specimens and the double disc specimen.

6.2 Verification and adjustment of specimen clamps and alignment

6.2.1 Alignment

The alignment of the clamps, axial and transversal, should be verified to ensure that the specimens are not twisted or deformed in any manner.

To ensure uniform load distribution, the co-axial alignment of the upper and lower clamps, and their parallel alignment should be verified.

6.2.2 Verification of the clamping

A special calibration specimen (see Figure A.1) should be prepared for the verification and adjustment of clamping devices to ensure the uniformity of the loading over the length of the specimen. The verification should be carried out in the same position as the tests. The magnitude of the strains, ε_l, at different positions – bridges – on the calibration specimen, Annex A should be measured using the applied strain gauges. Note that the when manufacturing the calibration specimen, the dimensions of the bridges, cross sections and lengths, should be as accurate as possible to ensure uniform stiffness of the specimen. The cross-sections of the bridges are required for calculating the strains at each of the bridges.

The verification should also be conducted at 90° and 180° rotation of the clamps to ensure symmetry between the upper and lower clamps.

The degree of non-uniform loading, ΔP_i, expressed as a percentage, is defined as Formula (1):

$$\Delta P_i = \frac{\varepsilon_i - \varepsilon_m}{\varepsilon_m} \times 100 \tag{1}$$

where

ε_i is the strain measured at bridge position *i* on the calibration specimen;

ε_m is the average strain measured on the calibration specimen.

Strain ε_i at a bridge position i should be measured with a well-designed calibration specimen (see Annex A).

$$\Delta P_{max} = \frac{\varepsilon_{max} - \varepsilon_m}{\varepsilon_m} \times 100 \tag{2}$$

where

ε_{max} is the maximum strain measured on the calibration specimen at bridge ***i***;

ΔP_{max} is the maximum value of ΔP_i.

The maximum value of non-uniform loading, ΔP_{max}, see Formula (2), should not exceed ±2 % for any given varying load. Further, the load distribution should not show minimum or maximum loading at either the ends or in the middle.

If the result of the verification does not satisfy the above limits, the clamping device should be adjusted or replaced by a new one.

If the clamps are being used for the first time, check their dimensional accuracy and the cleanliness and freedom of burrs on the mounting surfaces, the uniform tightening of the mounting nuts and bolts. Other possible reasons for non-uniform loads can be eccentric, angular, transverse or longitudinal misalignment in the positioning of the clamps. If the calibration specimen is being used for the first time, its geometry, in particular the position, accuracy and tolerances of the cross-sections and lengths of the connecting bridges should be checked.

When the tests are to be carried out with modified clamps, the specified non-uniform loading should also be verified with the same calibration specimen.

The calibration specimen should be calibrated at least every half year.

NOTE Design, material and manufacturing procedure of the calibration specimen are given in Reference[24].

6.3 Clamping device design

6.3.1 General

The clamping device for the standardised H–shear and –peel specimens, Figure C.1, was designed to ensure that the distribution of tensile load over the length of the device is uniform. This ensures that all joints are subjected to uniform loading. In addition, the clamping device is designed to enable the testing of specimens made using any commonly used mechanical joining or welding technology.

The standard clamping device consists of two clamps; an upper part and a lower part. The clamps were originally designed for test specimens made of deep drawing and conventional high strength steels as well as aluminium alloys with a sheet thicknesses between 0,5 mm and 3,0 mm. For aluminium specimens with a sheet thickness greater than 3,0 mm and for steel specimens for which the bend radii are greater than those given in the tables, the overlap requires modification, see Table 2 and Table 3. The clamps are shown in Annexes B and C. It is of the utmost importance to manufacture the clamps in accordance with the given tolerances to ensure optimum loading conditions.

As is to be seen in Figure C.1, the two clamps have different thicknesses. One clamp is 75 mm thick, the thickness of the other one is 63 mm. The reason for the different thicknesses is that when testing tensile shear specimens, one would have to use shims for the tensile shear specimens on the side with the flat coupons because the inside width of the specimen is 75 + 2*t*. The use of shims with the same thickness as the U-part would have the disadvantage that the flat side member would interface with the smooth surface of the shim with the danger of slippage occurring under load. Since the thickness of the shims is generally small, it would not be possible to serrate the outer surfaces of the shims. To ensure that there is no slippage between the specimen and the clamps, it is necessary to insert a spacer between the shim and the 75 + 2*t* wide specimen. This spacer has a thickness of 6 mm, because this is about the smallest thickness on which serrations can be machined on both sides. Another advantage of using 6 mm spacers as standard is that these spacers can be used for all specimens together with shims of U-member sheet.

In order to qualify the clamping device for the testing of specimens made of AHS and UHS steels, the mandrel for mounting the clamp in the testing machine should have an M48x1 metric fine thread.

All surfaces on the clamps which are in contact with the test specimen should be serrated in order to increase friction and thereby prevent slippage.

Precaution should be taken to avoid damage to the specimens and the load cell during tightening. A stepwise increase of the torque in three steps is recommended.

The prescribed torque, 150 Nm, is necessary to prevent slippage during the testing of thicker gauge specimens and joints with higher strengths. As an alternative, a hydraulic clamping device, Figure B.1 may be used instead of screws (see Annex B). The hydraulic pressure required depends on the diameter of the cylinders.

6.3.2 Example of suitable clamping device design

In the case of tensile shear loading with single- and two-joint specimens shown in Figure 4 and Figure 5, either standard mechanical clamps or hydraulically actuated clamps with a width of at least 50 mm should be used. It should be ensured that the specimen is clamped such that the joints lie in a line normal to the applied load and that the load is applied along an axis either passing through the centre of the single joint or is equidistant to the two joints. No slippage is allowed between the clamps and the specimen.

In the case of multi-joint tensile shear and multi-joint peel specimens, Figure 6 and Figure 7, it is recommended that the same clamps be used as for the H-specimens. With the use of these clamps, a uniform load distribution is ensured, because the clamps and the specimens have the same width. Care should be taken that the joint line is normal to the applied load. This can be ensured by using suitable positioning jigs.

In the case of tensile shear tests with H-specimens, Figure 8, one clamp with a thickness of, 75 mm, is clamped to the U-bent part of the test specimen. For the opposite part of the specimen, the clamp thickness is 63 mm. Mount spacers on both sides of the 63 mm clamp to compensate for the sheet thickness of the U-bent part, i.e. the spacer should have a thickness of (6 + *t*) mm where *t* is the sheet thickness (assuming that the sheet in the U bent part is *t* mm thick). Alternatively, a spacer with 6 mm thickness may be used together with a sheet-spacer with the same thickness as the "U". The 6 mm thickness or thicker spacers should be serrated on both sides to prevent slippage.

In the case of three-point bending tests on hat and closed profile specimens shown in Figure 10, Figure 11 and Figure 12, the load distribution over the length of the specimen is undefined and non-uniform and the loads in the individual joints also differ in their shear and peel components. In addition, the types and magnitudes of the individual shear and peel components change with the materials and thicknesses of the components. Generally, the loading is lowest in the joints near the clamped ends and highest in the middle. In addition, the results depend to a large extent on the clamping and how the load is applied. Therefore, the results of such tests, at best, give information on the performance of the particular specimen under the given boundary conditions but little information about the performance of the joints.

In the case of hat specimens and closed profiles under torsion loading, Figure 10, Figure 11 and Figure 12, the load distribution in the joints is undefined and non-uniform, varying with the sheet thickness and material combination. The results of such tests can only be used for comparing the specimens with one another but not for evaluating the load-carrying properties of the mechanical joints. As in the case of three-point bending tests, the highest stresses are experienced in the middle of the profile; the stresses near the ends are minimal because the clamping hinders any relative movement between the joined parts.

In the case of double disc specimens shown in Figure 13, the external load can be a tensile load, a torque or a combination of both. In all cases, joints are subjected to uniform loading, its type being defined by the type(s) of external load(s) and their magnitudes(s). The combinations of the shear and peel loads experienced by the joints depend on the magnitudes of the tensile load and the torque applied. These specimens allow the investigation of the load carrying ability of joints under defined singular and complex loads. In addition, the influence of material and material thickness combinations, joint type, joint size, joint orientation, pitch, edge distance, etc. can also be investigated.

The geometry and dimensions of KS-2 specimens are shown in Figure 14 and Table 9. The maximum sheet thickness is 5,0 mm. The maximum bend radius should be smaller than or equal to the maximum value given in Table 9. The testing of KS-2 specimens requires special clamps.

7 Testing procedure

7.1 General

The tests should be carried out at room temperature and a relative humidity of maximum 80 %

7.2 Testing machine

The tests should be conducted as load controlled tests at specified load ratios.

The selected testing machine should be calibrated in accordance with ISO 7500-1.

The machine should be checked at regular intervals to ensure that the desired form and magnitude of loading is maintained throughout the test (within ±1 % of the pre-set value). Because the clamps, see 7.3, are relatively heavy, the testing machine should be calibrated dynamically to eliminate the effect of mass forces. This is of utmost importance especially at higher testing frequencies, e.g. on resonance testing machines.

7.3 Mounting of clamping devices/clamps

As a first step, the clamping devices should be mounted in the testing machine such that neither the load cell nor the clamping devices are damaged. The clamping devices should be suitable for performing the planned tests. After mounting, uniform load distribution should be verified if required, see 7.2.

A pre-requisite for this is the alignment of the clamps before any tests are carried out.

7.4 Clamping procedure

The mounting procedure should be carried out such that neither the specimens nor the load cell are damaged. In the following, the clamping procedure for H-specimens is described by way of example.

The test specimen should be clamped such that no slippage can occur between the specimens and the clamps. To ensure that no slippage occurs between the clamps and the test specimen, M16 bolts, class 8.8 or superior should be used and tightened to at least 150 Nm of torque. Molybdenum disulphide, MoS2, should be applied to the threads and hardened washers should be used to minimize friction.

The specimens, should be clamped such that there is no twist, misalignment or axial displacement. A prerequisite for this is the alignment of the clamps as described under 7.2.

Specimens should be tested with the U-part in the upper clamping head. (It is assumed that the load cell is attached to the base plate of the machine.) The following clamping procedure should be followed:

— Position the H-specimen in the clamps as shown in Annex B.

— Place spacers of relevant thickness between the specimen and the lower and upper clamping heads, respectively. The spacers should be placed on both sides of the clamping head. The spacers should not be in contact with the specimen in the bend radius. These spacers are required for achieving alignment of the specimen in a position normal to the direction of the applied load.

— Start the testing machine and apply a low compressive force of approx. 3 kN to 5 kN to the specimen.

— Tighten the nuts to the prescribed torque using a torque wrench, for example, starting with the U, see 8.1. The sequence is from the middle towards the outside; first the U and then the side plates or the "ls" in the case of the peel specimens. The tightening of the nuts is to be carried out in three steps: 50 Nm, 90 Nm and 150 Nm. Alternatively, if a hydraulic clamping device is used, apply the prescribed hydraulic pressure, see Annex B.

— Remove the compressive force, apply a similar tensile force and remove the spacers for aligning the specimens.

The specimen, which has the same length as the clamping head, should be mounted flush in the longitudinal direction.

7.5 Fatigue testing

7.5.1 General

The fatigue test should be carried out at a constant load amplitude and a specified load ratio, R. The R-value for shear loading can be either positive or negative. For peel loading, the R-value should be positive.

Care should be taken not to overload the specimen at the start of the fatigue test. This risk can be minimized by a stepwise increase of the load amplitude.

The test load should be monitored continuously in the early stages of the test and periodically thereafter to ensure that the desired load cycle is maintained. The varying load, as determined by a suitable dynamic verification, should be maintained at all times to within 1 % of the pre-set value (peak loads).

The single and two joint shear specimens are, however, especially in the case of thinner sheet material, not suitable for tests in which compressive loads are employed, e.g. $R = -1$ or for variable amplitude tests.

The suitability of single and two joint peel specimens for fatigue tests, especially with thin gauge material is questionable, because the results obtained with such specimens are of very limited use.

The specimen length between clamps should be the same for the specimens being compared.

NOTE The dimensions for the specimen width and the overlap have been specified to ensure the data generated is usable for design purposes. Smaller widths and overlap could result in lower values and thus give misleading information. Shorter coupons may be used depending on the clamps of the testing equipment. The specimen length between clamps should not be changed.

Fatigue tests with single joint specimens may be carried out with tensile shear specimens, see ISO 18592 and ISO 14324.

7.5.2 Setting load conditions for the fatigue testing

The fatigue test should be performed as a constant amplitude mode test. The following load values should be agreed before testing by a JPS (Joining Procedure Specification) or by the contracting parties:

— F_{max};

— F_{min};

— load ratio;

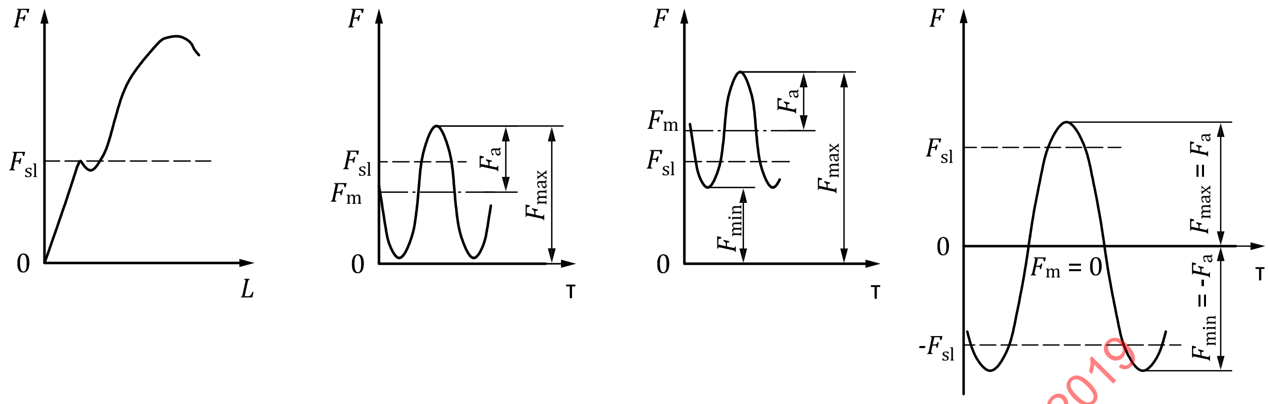
— load increments (the increments between the load levels for the test should be such that the line of best fit as determined by linear regression, can be calculated over a range of at least two orders of magnitude, e.g. between 5.10^3 to 5.10^5.);

— figures for repeating of the test.

However, with fatigue test specimens with mechanical joints, there is a possibility of slippage during testing. This phenomenon may greatly influence the test results. Therefore, tensile shear tests with single joint specimens, should be carried out prior to the fatigue tests to determine the possibility of slippage during fatigue testing, Figure 15 a).

If slippage is detected during tensile shear testing (see load vs. crosshead displacement/elongation diagram, Figure 15 a), performed prior to the fatigue tests, the load level at which slippage will occur in fatigue tests will, due to the influence of vibration which reduces friction and the so-called stick-slip effect, generally be lower.

Figure 15 b) shows load vs. time diagrams of constant amplitude fatigue tests with different load ratios. The fatigue behaviour of mechanically joined specimens should be investigated under load conditions as they are to be expected in the field.



a) Tensile shear test diagram | b) Constant amplitude fatigue test — Case I | c) Constant amplitude fatigue test — Case II | d) Constant amplitude fatigue test — Case III

Key

L	crosshead displacement/elongation	τ	time
F_{min}	minimum load	F_m	mean load
F	force/load	1	load at which slippage occurs
F_{sl}	slippage load	F_{max}	maximum load
F_a	load amplitude		

Figure 15 — Tensile shear test diagram and Load vs. Time diagrams of constant amplitude fatigue tests with different load ratios

NOTE For more information on the fatigue test, see ISO 18592.

Case I: Load Ratio, R = 0,1 ($R = F_{min}/F_{max}$) as shown in Figure 15 b).

The mean load, F_m, is applied and then the load amplitude, F_a, is super-imposed. During the actual test, friction lock or the slippage load level, F_{sl}, is exceeded in the first load cycle and, therefore, goes unnoticed as the test is continued.

Case II: Load ratio, R = 0,6 as shown in Figure 15 c).

Since the mean load is higher than the friction locking limit or slippage load, F_{sl}, this is exceeded during the application of the mean load, F_m.

During the actual fatigue test, no further slipping is registered and, therefore, goes unnoticed.

Case III: Load ratio, R = −1 (alternating load) as shown in Figure 15 d).

The load amplitude, F_a, is greater than the slippage load, F_{sl}.

Play is overcome in each load cycle because both the negative and the positive load amplitudes ($-F_a$; $+F_a$) are higher than the slippage load, F_{sl}.

Results from single joint tests should not be used to predict the behaviour of similar joints in assemblies on a one-to-one basis.

Since such fatigue tests are generally carried out as constant amplitude tests, the load amplitude will remain constant, even though the integrity of the joint has deteriorated. In order to determine the occurrence of slippage, both the mean displacement L_m, i.e. the displacement at mean load F_m and the displacement amplitude should be monitored as these change when slippage occurs.

In order to obtain universally comparable test results, independent of the type of testing equipment, the use of a failure criterion applicable on all types of testing equipment is recommended, e.g. relative load-displacement ratio or percentage or stiffness loss which shows a very good correlation with the deterioration of the integrity of the joint during testing.

If a magnetically actuated resonance-type testing machine is used for the tests with negative load ratios, *R*, i.e. tests with alternating loads, the test will generally be terminated by the machine because the controls cannot ensure constant force amplitudes when slippage due to play occurs.

If servo-hydraulic or mechanically actuated testing machines are used, the test will not be terminated automatically if slippage occurs. This will, however, be accompanied by an increase in noise level.

7.5.3 Test frequency

The tests should be carried out at frequencies which have a negligible effect on the fatigue life.

The testing frequency of mechanically joined specimens generally lies between 30 Hz and 140 Hz and depends on the stiffness of the specimen and the type of testing machine being used. Tested specimens can show an excessive increase in temperature if the testing frequency and/or the load amplitude are too high. The temperature of the specimen should be monitored since an increase in temperature can have an adverse effect on the test result. If required, suitable measures should all be taken to avoid an increase in temperature. In the case of temperature sensitive Hybrid joints, e.g. mechanical joints plus adhesive bonding, plastics, etc., the testing frequency should be selected such that the increase in temperature is not higher than 2 °C. The testing frequency should in the case of structural adhesive bonded joints, as recommended in ISO 9664, not exceed 30 Hz.

When testing visco-elastic materials, e.g. adhesives, the thermal effects can have a large negative influence on the fatigue life. Therefore, tests should be performed to verify the effect of test frequency on specimens which include adhesive bonding.

7.6 Test termination

7.6.1 General

The test should be terminated when the specified failure criterion, the endurance limit or the fatigue limit is reached. The failure criterion is based on the loss of integrity of the specimen and is noticeable as a loss of stiffness of the test specimen. As the test is conducted at constant load amplitude, the stiffness loss can be evaluated from the change in displacement amplitude or a decrease in testing frequency.

The following failure criterion are applicable to the fatigue testing of mechanical joints.

The test should be terminated when:

a) slippage or permanent setting occurs;

b) a 40 % increase in the displacement amplitude is registered;

c) a 40 % stiffness loss; or

d) a criterion agreed prior to the beginning of the test is fulfilled.

NOTE A value other than 40 % may be specified.

When resonance testing machines are used, stiffness loss can be detected as a change in test frequency. However, this does not apply to other types of testing machines and is therefore not recommended as a failure criterion because the results will not be comparable.

The failure criterion is based on relative stiffness loss C_{Lrel},calculated at N number of load cycles as Formula (3):

$$C_{\mathrm{Lrel}} = \frac{C_0 - C_N}{C_0} \tag{3}$$

The displacement can thus be measured either directly on the specimen or as a relative displacement of the clamps.

Stiffness loss C_{LN}, at N load cycles, is (C_0 − C_N). This term divided by C_0 is the relative stiffness loss, multiplied by 100 is the percentage stiffness loss.

As a reference (100 % stiffness), the stabilized stiffness value, C_0, should be used. Stabilization usually occurs relatively soon after the start of the test, see Figure 16.

In cases in which a stable condition is not achieved, a stiffness value calculated at either 10 s or at 500cycles after the start of the test, whichever occurs earlier should be used as the initial stiffness.

NOTE 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 % or, the stiffness shows a continuous linear over a period of 10 s or 500 cycles, whichever occurs earlier.

The failure criterion to be used depends on, for example, the joining method and on the field of application or the design criteria. Therefore, the test should be continued until a sufficient drop, in the stiffness loss (e.g. 40 %) has been reached.

7.6.2 Failure criterion and number of cycles to failure

In constant amplitude load-controlled fatigue tests, the displacement range increases with crack initiation and crack propagation both of which lead to a loss in specimen stiffness. For a defined loss of stiffness as a failure criterion, e.g.

$$\frac{(\Delta L - L_0)}{L_0} = 40\,\% \text{ and } \frac{(C - C_0)}{C_0} = 28{,}6\,\%$$

$$\frac{(C - C_0)}{C_0} = -28{,}6\,\% \text{ or } \frac{(C - C_0)}{C_0} = -40\,\%$$

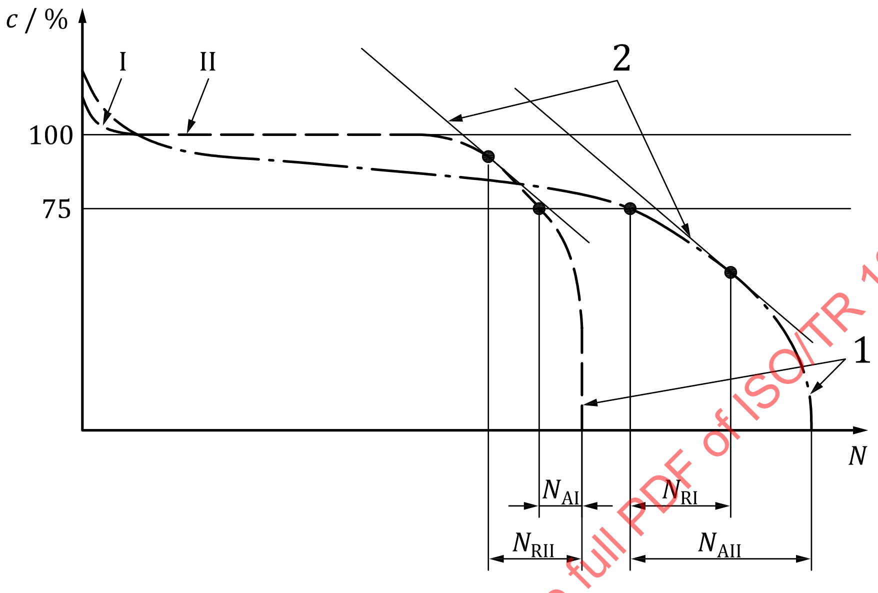
the number of cycles to failure corresponds to a specimen displacement of

$$\frac{(\Delta L - \Delta L_0)}{L_0} = 40\,\% \text{ or } \frac{(\Delta L - \Delta L_0)}{L_0} = 67\,\%$$

From a design point of view, it is not only the relative decrease in stiffness that is decisive, but also the rate of stiffness loss. The number of cycles to failure, therefore, is defined as the life until the integrity (stiffness) has dropped to a pre-set value or when the rate of integrity loss (rate of stiffness loss) exceeds a specific value. The criteria to be used for the evaluation should be agreed after consultation with the responsible design department before the test is conducted.

The failure criterion to be used depends, for example, on the application. In the aircraft and aerospace industries, where regular checks are mandatory and detailed knowledge about crack initiation and crack propagation is available, the failure criterion can be a crack with a defined length. For example, in the automobile industry, where no mandatory checks can be specified, the appearance of the first visible crack is a suitable failure criterion. Since cracks can occur at locations which are either not or not easily accessible, the corresponding stiffness loss should be correlated to the relevant failure criterion. In the case of the different mechanical joints, it is advisable to correlate the visible crack length with a 40 % loss in stiffness before using this as a failure criterion.

The reason for introducing a new parameter, the rate of integrity loss (stiffness loss) for the failure criterion is shown in Figure 16. Two specimens exhibiting an identical relative decrease in stiffness can have a great difference in their residual lives. In Figure 16, the residual life is defined as the number of cycles between 75 % relative stiffness and total fracture or the number of cycles between the specified rate of stiffness loss and total fracture. Experience concerning the importance of this parameter, stiffness loss, is limited. The initial testing with different kinds of materials, different joining methods, etc., has thus to show which parameter is more suitable.



Key

1 complete separation of the specimen

2 slope, equal to, $\left(\frac{d{c_{rel}}^2}{dN^2}\right)$ i.e. rate of stiffness loss

N_{AI}, N_{AII} number of load cycles using absolute stiffness loss as failure criterion for the two specimens

N_{RI}, N_{RII} number of load cycles using relative (percentage) stiffness loss as failure criterion for the two specimens

NOTE I and II denote stiffness evolutions for two different specimens.

Figure 16 — Fatigue life using: a) absolute stiffness, b) relative stiffness loss or c) rate of stiffness loss as failure criteria

7.6.3 Stiffness

The stiffness value (see 3.18) should be calculated based on a linear relationship between displacement and load, since it is assumed that the test is to be carried out in the elastic range.

The displacement amplitude should be measured accurately. The displacement transducer (clip-on gauge, etc.) used should have a resolution of at least 0,05 mm/V (shear specimen).

7.6.4 Data acquisition

To enable a more detailed analysis of the data at a later stage, load and displacement amplitude values, together with the corresponding number of load cycles should be stored. A flow chart, showing an example of a data acquisition sequence during a fatigue test is shown in Annex D. The data acquisition, in accordance with Annex D, gives between 200 and 400 stiffness values for each specimen. With the current state of the art, at least 1 000 "stiffness per number of cycles" values should be stored for later analysis.

7.7 Re-testing

If the specimen component or test piece fails to comply with the requirements of the visual examination, one further specimen component or test piece should be tested after adjustment of the joining equipment. If the test results of this additional specimen component or test piece also do not comply with the requirements, the joining procedure test has failed.

If any test specimen fails to comply with the requirements for destructive tests, two further specimens should be tested. Each additional test specimen should be subjected to the same tests as the failed test specimen. If either of the additional test specimens does not comply with the requirements, the joining procedure test has failed.

8 Test report

8.1 Basic information

8.1.1 General

Fatigue test results can be significantly influenced by the properties and history of the parent material, operations during the preparation of the fatigue specimens, and the testing machine and the test procedure used to generate the data. The presentation of fatigue test results should include basic information on the material, specimens and the testing procedure to increase their usefulness and value and thus to minimize the risk of misinterpretation or improper application.

8.1.2 Material prior to fatigue test specimen preparation

The minimum information to be presented should include the designation or specification of the material, nominal thickness and the chemical analysis.

8.1.3 Mechanical properties

The minimum data on the mechanical properties of the material, in a condition identical to that of the fatigue test specimen, should include the tensile strength, yield point or yield strength and the fracture elongation.

8.1.4 Specimen design and preparation

There should be a drawing of the shape and dimensions of the fatigue test specimen. Ensure that all operations performed in preparing the specimens are reported.

8.1.5 Test procedure

If statistical techniques were used to design the fatigue test programme, the design plan and list of statistical techniques (e.g. randomization of test sequence, blocking) used should be described.

NOTE Statistical techniques are described in EN 10130, EN 10346, and ASTM E468.

8.1.6 Fatigue testing machine

Minimum information should include the type of testing machine, the functional characteristic (e.g. electro-hydraulic, resonance), frequency of load application, nominal load range of machine, minimum and maximum displacement, minimum and maximum load amplitude, testing frequency, nominal load of load cell, type and resolution of transducer. If tests were performed on more than one machine, the number and type of the testing machines used should be given.

All test results to be plotted in the same F-N diagram should be performed on the same machine and with the same equipment, e.g. load cell, clamps, etc.

8.1.7 Ambient conditions during the fatigue test

Minimum information to be presented should include the average value and ranges of both the temperature and relative humidity observed in the laboratory during the test programme. This information is of particular importance in the case of high cycle fatigue tests.

Considering bonded specimens, the storage and testing conditions (temperature, humidity) should be given.

8.1.8 Results of post-test examination

For each test specimen, the reason for terminating the test, e.g. fulfilment of the demands of the failure criterion or run-out (fatigue or endurance limit), and, if applicable, a description of the appearance of the fractured surface and the location of the crack initiation should be given.

8.2 Presentation of fatigue test results

8.2.1 Tabular presentation

The fatigue test results should be reported in tabular form. The tabular presentation should include:

a) specimen identification;

b) test sequence;

c) dynamic loads (any two of the following):

   1) maximum load;

   2) minimum load;

   3) mean load;

   4) load amplitude or load range; and

   5) load ratio;

d) fatigue life or cycles to end of test;

e) reason for terminating the test;

f) results of the post-test examination (see 8.1.8).

If the test frequency varies from specimen to specimen, it should also be included in the tabular presentation.

8.2.2 Graphical presentation

The fatigue test data may be presented graphically as a *F-N* (Load vs. Cycles) diagram. Both variables are plotted on logarithmic scales; the dependent variable, fatigue life, N, in cycles, is plotted on the abscissa, and the independent variable, *F*, representing maximum load, load amplitude or load range, in Newtons [N] or Kilonewtons [kN], is plotted on the ordinate. A line is fitted by linear regression analysis to the fatigue data or approximated visually. If data are fitted by regression analysis, the equation for the Load vs. Cycles diagram and the corresponding statistical scatter should be presented.

NOTE Investigations have shown that the differences in the results of regression analysis and visual approximation are generally minor.

