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Resistance welding — Destructive testing of welds — Method for the fatigue testing of multi-spot-welded specimens

Soudage par résistance — Essais destructifs des soudures — Méthode d'essai de fatigue des échantillons soudés par points multiples

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 18592 was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 6, *Resistance welding and allied mechanical joining*.

Requests for official interpretations of any aspect of this International Standard 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.

Introduction

This International Standard has been prepared because welding engineers (and most design engineers) are not familiar with fatigue testing and the influence of factors such as load type (e.g. shear load, peel load), and failure criteria.

Tests are used to investigate the existence of specific properties and their qualitative and quantitative evaluation. Fatigue tests, in general, are used to investigate the behaviour of structures and components subjected to cyclic loads. For welded components, fatigue tests are used to determine the influence of different parameters such as joining methods, pitch, material thickness and material combinations type of load (e.g. shear load, peel load), overlap, location of weld on flange, edge distance, loading condition (e.g. quasi-static, cyclic, load ratio R), and the combination of environment and corrosion on the fatigue behaviour (life) of spot welds and/or specimens subjected to various types of loads. Fatigue tests should, if their results are to be used for design purposes, as far as possible, take into consideration such boundary conditions as encountered in a real life environment. This applies to load types, load amplitudes, and load ratios as well as load distributions and failure criteria (Reference [7]).

The test specimen selected for the fatigue test should simulate, as closely as possible, the loads and the boundary conditions as they are encountered in service. Furthermore, the failure criterion used should conform to the application in hand. Although the type of primary load is identical in some specimens, e.g. shear load in flat multi-spot specimens, shear H-specimens, KS-2 specimens, and double disc specimens, the results of fatigue tests differ significantly because of the secondary load types resulting from varying degrees of local deformation due to the differences in the local stiffness in the area of the joints. The local deformation, responsible for the magnitude of the peel component, for example, is a function of the local stiffness, increasing with a decrease in stiffness.

This International Standard offers a framework within which the different specimens, described herein, can be modified such that design specifics and production constraints, e.g. flange width and overlap, weld nugget size, pitch, bending radius, and sub-standard welds, can be given due consideration. This helps towards enhancing the significance of the results very appreciably.

Note that if welds could be subjected to identical amplitudes of shear and peel loads, their lives would differ by a factor of approximately 10^4 (References [8] to [11]). This explains the necessity to use different specimens for the simulation of different load types.

Conformance tests on *real* components serve the verification of design calculations and are necessary for the qualification of structures. It is therefore necessary to maintain their number at an absolute minimum.

Resistance welding — Destructive testing of welds — Method for the fatigue testing of multi-spot-welded specimens

1 Scope

This International Standard specifies test specimens and procedures for performing constant load amplitude fatigue tests on multi-spot-welded and multi-axial specimens in the thickness range from 0,5 mm to 5 mm at room temperature and a relative humidity of max. 80 %. The applicability of this International Standard to larger thicknesses can be limited by mechanical properties such as yield strength and formability of the specimen material. The thickness range for advanced high strength steels (AHSS) is generally below 3,0 mm. Greater thicknesses apply for aluminium alloys, for example.

Depending on the specimen used, it is possible from the results to evaluate the fatigue behaviour of:

a) spot welds subjected to defined uniform load distribution;

b) spot welds subjected to defined non-uniform load distribution;

c) spot welds subjected to different defined combinations of shear-, peel-and normal-tension loads; and

d) the tested specimen.

Multi-spot specimens with which the different load distributions can be realized are:

1) defined uniform load distribution:

i) H-specimens for shear- and peel-loading, (welds subjected to uniform shear or peel loading transverse to the joint line),

ii) single- and double-hat specimens subjected to four-point bending (spot welds subjected to uniform shear load in the direction of the row of welds),

iii) double-disc specimen under torsion (spot welds subjected to uniform shear load),

iv) double-disc specimen under tensile load (spot welds subjected to uniform peel load),

v) double-disc specimen under combined torsion and tensile loading,

vi) flat multi-spot specimens using defined grips;

2) defined non-uniform load distribution:

i) H-specimens with modified grips,

ii) modified H-specimens with standard grips,

iii) modified H-specimens with modified grips,

iv) flat multi-spot specimens with modified grips,

v) modified multi-spot flat specimens with standard grips,

vi) modified multi-spot flat specimens with modified grips;

3) defined combinations of shear-, peel- and normal-tension loads:

i) the KS-2 specimen,

ii) the double disc specimen;

4) spot welds subjected to undefined non-uniform load distribution — single-hat, double-hat and similar closed hollow sections under torsion, 3-point bending and/or internal pressure.

The specimens and tests referred to under 4) are not dealt with further in this International Standard, because the results obtained with these specimens are specific to the components as tested and may not be generalized or used for deriving data pertaining to the load-carrying behaviour of the welds. Results obtained with such tests are suitable for comparing the mechanical properties of the tested components with those of similar components tested in the same manner. These tests are, however, *not suitable* for evaluating or comparing the load-carrying properties of the welds.

The test results of the fatigue tests 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 a fatigue test are suitable for *direct* application to design only when the loading conditions in service and the stiffness of the design in the joint area are identical.

NOTE Specimens are modified to take into consideration constraints or specific demands posed by design, e.g. smaller than standard overlap, smaller or larger than standard nugget diameter, and specific load distribution, thus enhancing the value of the test results for the design engineer.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14273, *Specimen dimensions and procedure for shear testing resistance spot, seam and embossed projection welds*

ISO 14324, *Resistance spot welding — Destructive tests of welds — Method for the fatigue testing of spot welded joints*

ISO 15609-5:2004, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 5: Resistance welding*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14324 and the following apply.

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

NOTE Adapted from ISO 14324:2003, 3.12.

3.2
maximum load
F_{max}
highest algebraic value of the repeated load

NOTE Adapted from ISO 14324:2003, 3.9.

3.3
minimum load
F_{min}
lowest algebraic value of the repeated load

NOTE Adapted from ISO 14324:2003, 3.11.

3.4
load range
ΔF
difference between maximum and minimum loads

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

NOTE Adapted from ISO 14324:2003, 3.8.

3.5
load amplitude
F_a
half of the load range

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

NOTE Adapted from ISO 14324:2003, 3.6.

3.6
mean load
F_m
average of maximum and minimum loads

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

NOTE Adapted from ISO 14324:2003, 3.10.

3.7
load ratio
R
minimum load divided by the maximum load

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

NOTE Adapted from ISO 14324:2003, 3.7.

3.8
fatigue life
number of cycles to failure
N_f
number of cycles which can be applied at a specified repeated load before failure occurs

NOTE Adapted from ISO 14324:2003, 3.3.

3.9
fatigue endurance
N
number of cycles at which it has been agreed to stop the test even if failure does not occur

3.10
F-N **curve**
curve obtained by plotting the load amplitude (or load range, or maximum load) as ordinate and the fatigue life (or fatigue endurance if the test is terminated before failure) as abscissa, also called the load-amplitude-number of load cycles curve.

NOTE 1 It is normal practice to use logarithmic axes.

NOTE 2 Adapted from ISO 14324:2003, 3.5.

3.11
S-N **curve**
curve drawn by plotting the stress amplitude (or stress range, or maximum stress) as ordinate and the fatigue life (or fatigue endurance if the test is terminated before failure) as abscissa, also called the stress-amplitude-number of load cycles curve.

NOTE The S-N curve is generally not suitable for spot welded specimens.

3.12
endurance limit
maximum load amplitude F_{max} at which a test specimen can endure a specified number of load cycles without failing

NOTE Adapted from ISO 14324:2003, 3.2.

3.13
fatigue limit at probability p
maximum load (range, amplitude or maximum value) at which the test specimen can endure an infinite number of load cycles with the probability p

NOTE Usually, the probability selected is 50 %.

3.14
endurance limit at probability p
load (range, amplitude or maximum value) at which the test specimen can endure a specified number of load cycles with the p probability without failing

NOTE The probability usually selected is 50 %.

3.15
displacement
ΔL
change in the length of a specimen due to the application of a load

3.16
stiffness
c
load F divided by the corresponding displacement L, i.e.

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

3.17
initial stiffness
c_0
stiffness at start of the test, i.e.

$$c_0 = \frac{F_{max} - F_{min}}{\Delta L_0}$$

4 Symbols and abbreviated terms

a	overlap
b	test coupon width
b_i	internal width of test coupon
b_s	width of side plate
c	stiffness
c_0	initial stiffness
d_c	diameter of central hole
d_e	diameter of pitch circle
e	pitch
F	load, repeated load
F_a	load amplitude
F_m	mean load
F_{max}	maximum load
F_{min}	minimum load
F_p	peel load
$F_{p,max}$	maximum peel load
$F_{p,min}$	minimum peel load
F_{pt}	peel load transverse to the joint line
F_s	shear load
$F_{s,max}$	maximum shear load
$F_{s,min}$	minimum shear load
F_{sp}	shear load parallel to or in the axis of the joint line
F_{st}	shear load transverse to the joint line
g	bar distance
h	outer height of hat-section
h_i	coupon 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

l_a distance between grip and overlap

l_c length of clamped area

l_e edge distance

l_f specimen length between clamps

l_g specimen length between grips

l_S total length of specimen

l_t length of test coupon

l_w distance from wall

L displacement

L_{max} maximum displacement

L_{min} minimum displacement

N number of load cycles

p probability

r_1 bend radius for sheet thickness t_1

r_2 bend radius for sheet thickness t_2

R load ratio

t time

t_1; t_2 sheet thicknesses

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

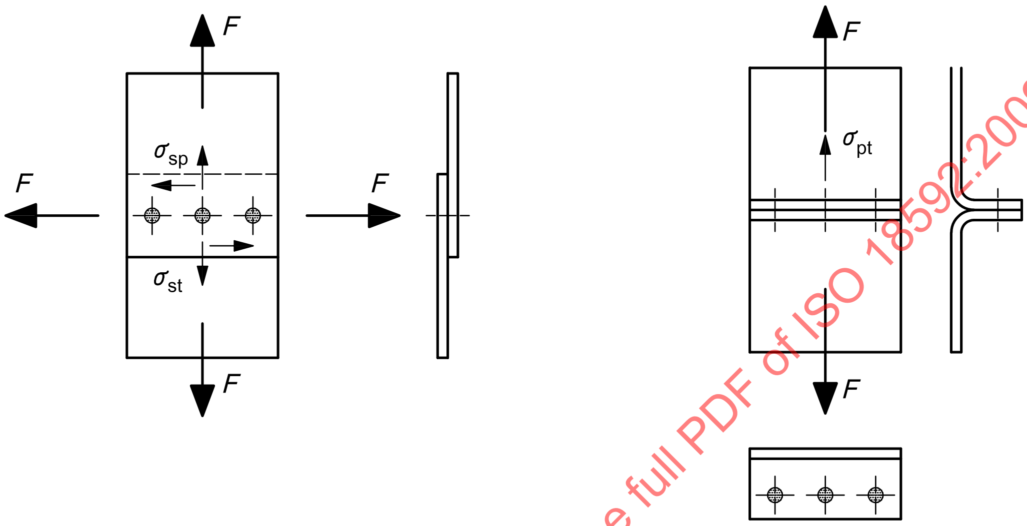
σ_{st} shear stress transverse to the joint line

ΔL displacement ($L_{max} - L_{min}$)

5 Specimens

5.1 General

The specimens are designed to simulate, for joints in thin-walled structures, three basic types of loadings 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).



a) Shear load transverse to the joint line and shear load in the axis of the joint line **b) Peel or one-sided cross-tension load**

NOTE See Clause 4.

Figure 1 — The three basic load cases for joints (Reference [9])

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 in the first paragraph either singly or in a pure form. For lap joints, at least one type of shear stress and, due to the local deformation of the sheets caused by it, peel stress 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 forces acting and the local stiffness. The stiffness itself is a function of the sheet thicknesses, the Young modulus of the material(s), the flange width, the overlap, the location of the joint on the flange, the bending radii, etc. (References [8] to [11]).

NOTE 2 The specimens have been designed to permit the use of different joining methods, e.g. spot welding, self-piercing riveting, clinching, friction stir spot welding, laser welding and GMA welding, and thus allow a comparison of the load-carrying properties of joints made with different methods.

NOTE 3 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 subclause 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.

The documentation should contain the following information.

a) Material(s)

— Material specification, type and thickness of coating(s), sheet thickness, surface condition and mechanical properties should be noted.

b) Coupons

— The coupons should, if possible, be taken from the same material lot.

— The rolling direction shall be identical for all coupons and documented.

— The required tolerances shall be adhered to.

— Unintentional deformation of the coupons and damage to the surfaces is to be avoided.

c) Welding

— Suitable jigs should be used to ensure accurate alignment of the coupons and location of the welds.

— The welding parameters and the equipment used shall be documented.

d) Documentation

— The relevant standards shall be referenced.

— Any deviation from the referenced standards shall be documented.

The specimens shall be modified for the different joining methods, such that the joints are able to perform under optimum boundary conditions, e.g. the flange width for laser welds can be reduced considerably as compared to the length required for resistance spot welds. Similarly, because of the smaller space requirements, the location of rectangular clinch joints on the flange can be much closer to the radius than is the case with resistance spot welds unless eccentric welding electrodes are being used.

5.2 Selection of suitable specimens

The selection of a suitable specimen for the fatigue tests depends on the planned usage of the test results. A basic requirement of the specimen is that it should allow the relevant load type 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 type of 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.

Besides considering the primary loading condition of the welds, bear in mind the local stiffness of the joint area in the component in question. *The fatigue life of welds is influenced decisively by the peel load and not by the shear load*. For example, if welds could be subjected to identical amplitudes of shear and peel loads, their lives would differ by a factor of ~10^4. However, as can be seen in Figure 2, spot welds under shear load would never fail under a load at which identical welds 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. Especially in the case of the single spot specimen, Figure 4, the local stiffness is much lower than is usual in real structures. Therefore the peel/shear ratio is comparatively large, resulting in a significantly shorter fatigue life as compared to identical welds tested on H-specimens, for example. In addition, some materials are particularly sensitive to peel stress in the as-welded condition, so that results obtained with specimens with a low stiffness can be misleading with regard to the behaviour of such welds in structures.

The H-specimens allow the investigation of almost all parameters including different stress ratios and stress distributions. They require special grips for testing and their manufacture 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:

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

— simulation of design parameters such as stiffness, pitch, edge and flange distance;

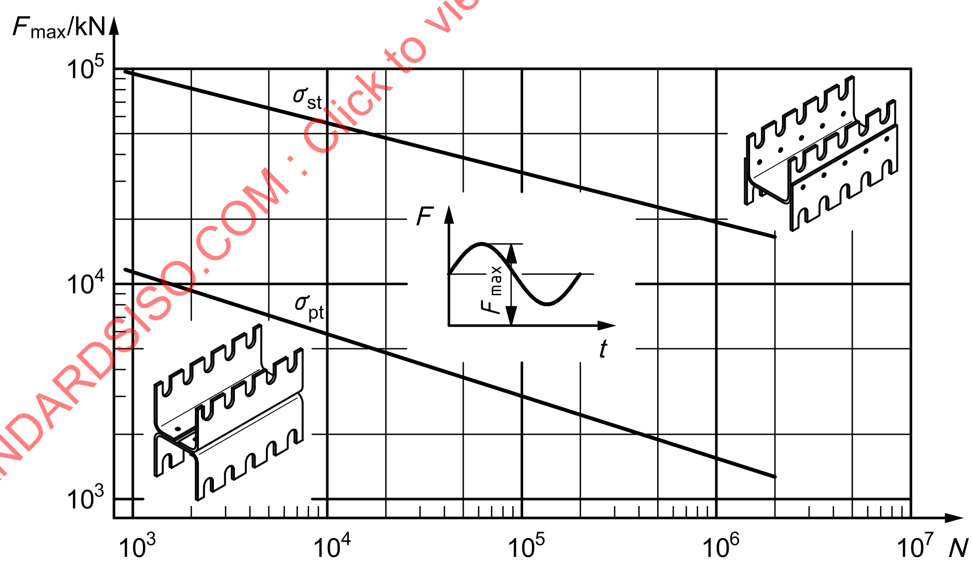
— simulation of the stress distribution in the component;

— effort required for manufacturing and testing;

— number of specimens required to obtain statistically significant results.

Note that results obtained with specimens with a low stiffness generally bias spot welded joints, especially in the case of high strength steels.

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 spot welds, for example, is five times greater than H- or double disc specimens with 10 spot welds. 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 compressive loads or negative load ratios R, e.g. two flat specimens with one or two welds.



NOTE See Clause 4.

Figure 2 — Wöhler curves of spot-welded H-specimens of 1 mm DC 04 steel sheet subjected to shear and peel loading, load ratio R = 0,1 (Reference [9])

5.3 Specimen fabrication

5.3.1 Sheet material

The sheet material for the coupons may be in the sheared condition, but all burrs should be removed. Care should be taken to ensure that the coupons are not bent or distorted. 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 the relevant tables.

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.

The bending of the components of the specimens shall be performed in a press brake to the required bending angle and radius, $R_{min} = 2t$. If the material employed does not allow this radius, it may be bent to R_{max}. Since the accuracy of the specimens depends on the dimensions of the coupons, ensure that the tolerances given in the tables are strictly adhered to.

The components of the double disc specimen require the use of drawing- or deep-drawing tools for their fabrication.

5.3.2 Bending and forming

The bending of the components of the specimens shall be performed in a press brake to the required bending angle and radius, $R_{min} = 2t$. If the material employed does not allow this radius, it may be bent to the R_{max}. Since the accuracy of the specimens depends on the dimensions of the coupons, to ensure that the tolerances given in the tables are strictly adhered to.

The components of the double disc specimen require the use of drawing- or deep-drawing tools 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.

The geometry of the specimens and the location, pitch and size of the spot welds may be modified such that design and manufacturing requirements can be taken into consideration. For example, the pitch, the nugget diameter, the flange width and the location of the weld on the flange can be modified if required. Suitable jigs should be used for positioning the coupons during welding and ensuring a precise location of the welds and uniform load distribution during testing.

The joining sequences for all specimens shall be from the centre of the specimen towards the edge, see Figure 3. The welding sequence for the different multi-spot specimens shall be such that enveloping is avoided. The diameter of all welds shall conform to the specifications. If necessary, increase the welding current to compensate for the effect of shunting.

For AHS steels, much larger bending and drawing radii are necessary. In such cases, it is necessary to modify the flange width and the location of the welds accordingly.

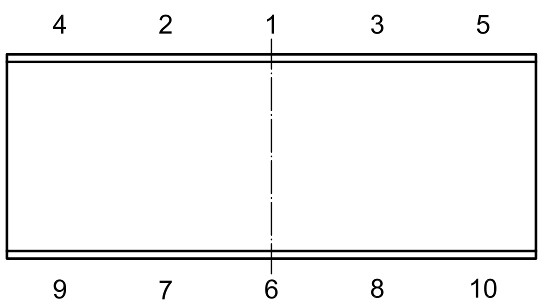


Figure 3 — Joining sequence for H-specimens

5.3.3 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 H- and KS-2 specimens, the inside width, and for hat specimens, the outside width, each have a tolerance of $^{+0,2}_{\ 0}$ mm. The flange angle is (90 ± 0,5)°.

5.3.4 Welding

All the parameters used for the fabrication of the specimens shall be documented (see ISO 15609-5:2004, Annex A) in the test report.

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

5.3.5 Storage

Specimens which are subjected to corrosion in air at room temperature should be protected accordingly, preferably in an inert medium. The specimen should be removed from the storage medium before testing, care being taken not to affect the specimen chemically.

5.3.6 Inspection

All the specimens shall 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. A gauge is recommended for the overall check of the dimensions.

5.4 Specimen geometry

5.4.1 General

The geometry of the specimens, and the location, pitch and size of the spot welds, should be modified such that design and manufacturing requirements can be taken into consideration. For example, the pitch, the nugget diameter, flange width, and the location of the weld on the flange can be modified if required. Suitable jigs should be used for positioning the coupons during welding and ensuring a precise location of the welds.

Several specimens are currently used in fatigue tests. The aim of this International Standard is to help the user to select specimens suitable for the task in hand:

a) single spot welded as specified in ISO 14273, see Figure 4;

b) flat overlap specimen with two spot welds, see Figure 5;

c) flat multi-spot specimens for shear and peel loads, see Figures 6 and 7;

d) H-specimens for shear and peel loading, see Figures 8 and 9;

e) single- and double hat specimens (under 4-point bending), see Figures 10 and 11;

f) various closed sections (under 4-point bending), see Figure 12;

g) double disc specimen, see Figure 13;

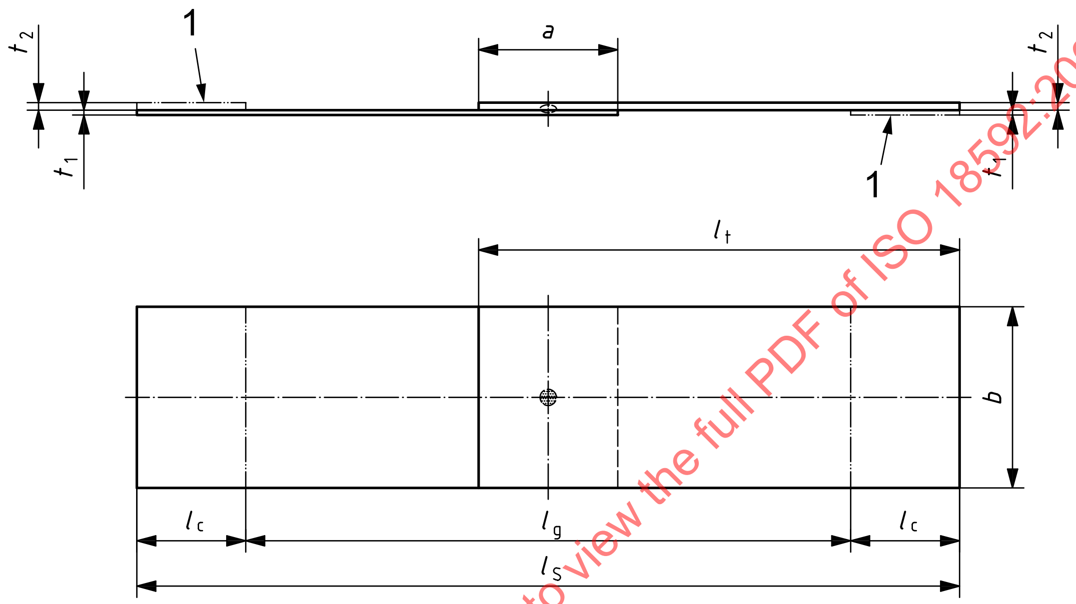
h) KS-2 specimen, see Figure 14.

The geometry and the dimensions of the different specimens are given in the corresponding figures and tables.

5.4.2 Specimen geometry of flat specimens

The flat specimens listed in 5.4.1 a) and 5.4.1 b) have a stiffness which is much lower than that of normal structures.

The flat specimens listed in 5.4.1 c) are stiffer and offer a number of advantages, 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 grips as the H-specimens listed in 5.4.1 d).



Key

1 shim plates are used to avoid misalignment when clamping the test specimen

NOTE 1 See Clause 4.

NOTE 2 For specimens consisting of sheets with unequal thicknesses, t_1, t_2, the sheet thicknesses given in Table 1 correspond to those specified for the thinner sheet.

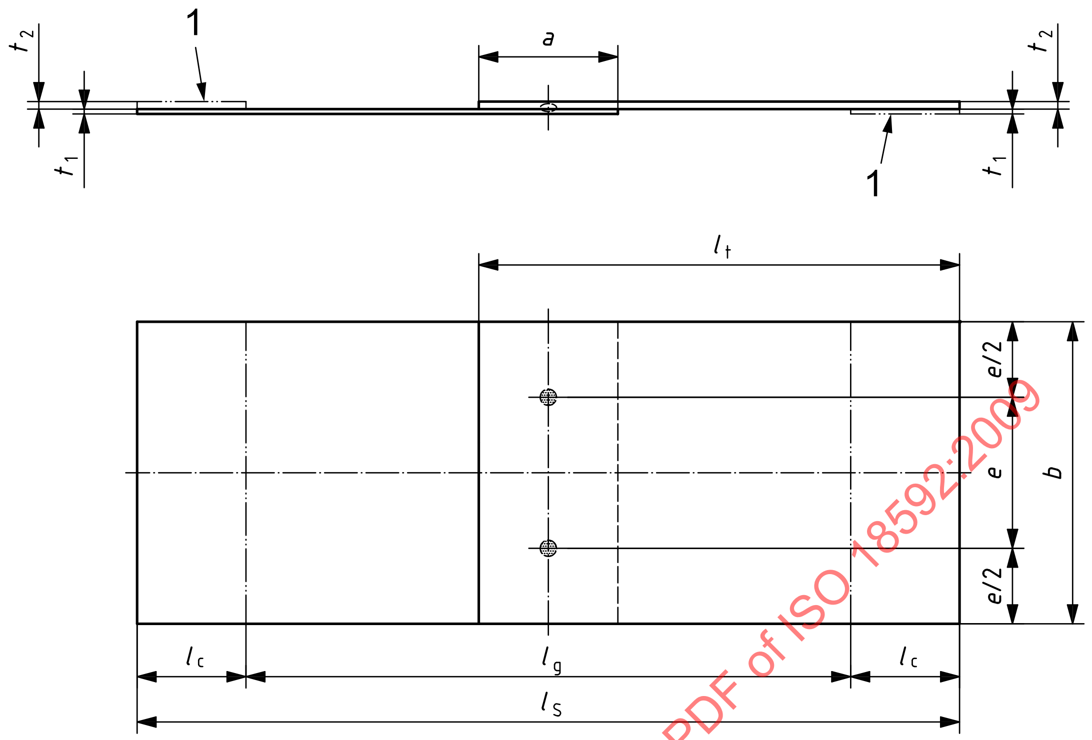
Figure 4 — Single spot specimen in accordance with ISO 14324

Table 1 — Dimensions of single spot specimen in accordance with ISO 14324

Dimensions in millimetres

Sheet thicknesses t_1, t_2	Width b	Overlap a	Total length of specimen [a] l_S	Specimen length between grips l_g	Length of single coupon [a] l_t
$0,5 \leqslant t \leqslant 1,5$	45 ± 0,5	35	⩾ 250	160	⩾ 142,5
$1,5 < t \leqslant 3,0$	60 ± 0,5	46	⩾ 320	200	⩾ 182,5
$3,0 < t \leqslant 6,0$	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 can be reduced correspondingly.



Key

1 shim plates are used to avoid misalignment when clamping the test specimen

NOTE 1 See Clause 4.

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

Figure 5 — Flat overlap specimen with two spot welds

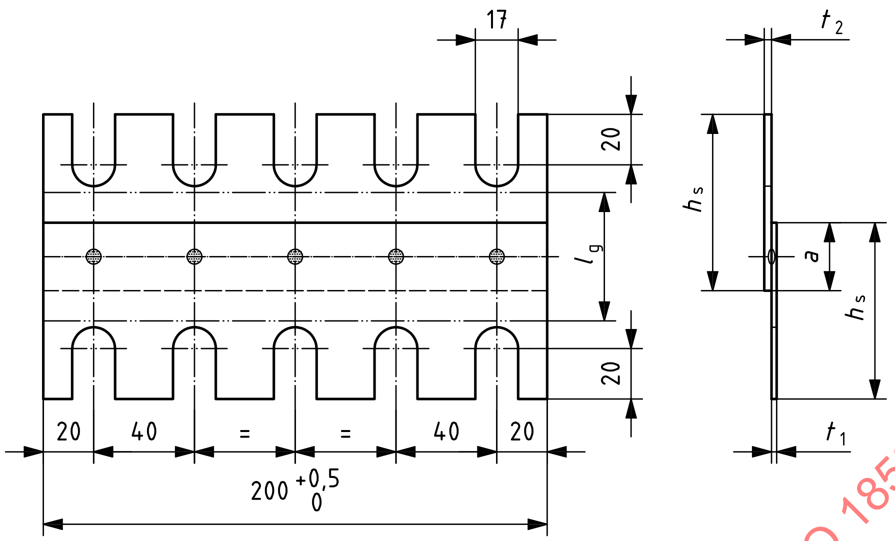
Table 2 — Dimension of flat overlap specimen with two spot welds

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 grips l_g	Pitch e
$0{,}5 \leqslant t \leqslant 1{,}5$	70	35	⩾ 167,5	⩾ 300	160	35
$1{,}5 < t \leqslant 3{,}0$	100	45	⩾ 222,5	⩾ 400	200	50
$3{,}0 < t \leqslant 6{,}0$	⩾ 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



NOTE See Clause 4.

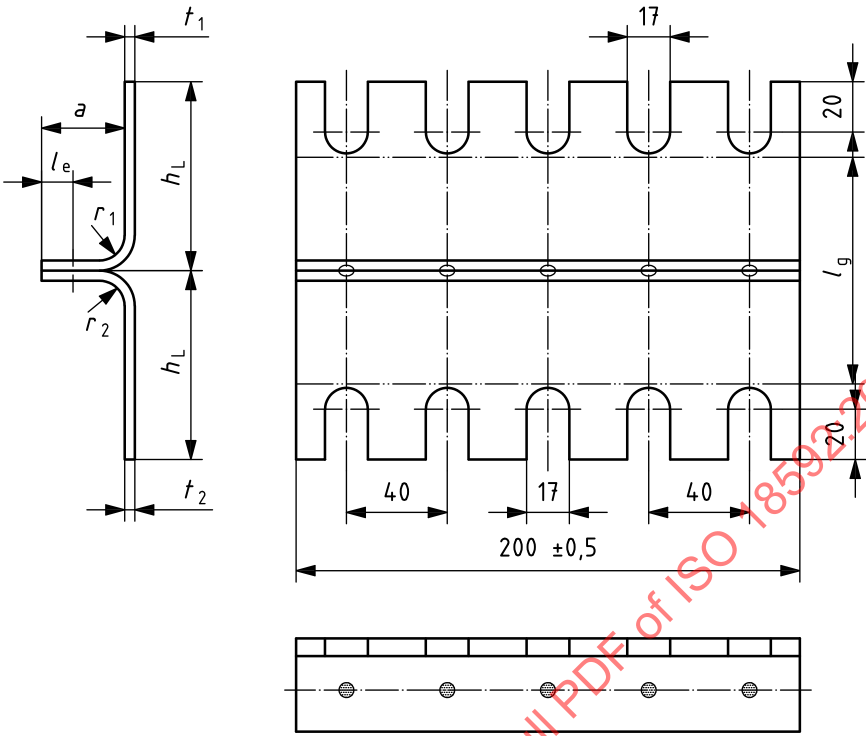
Figure 6 — Flat multi-spot shear specimen

Table 3 — Dimensions of flat multi-spot shear specimen

Dimensions in millimetres

Smallest sheet thickness t_1 or t_2	Overlap a	Specimen length between grips l_g
⩽ 1	16	40
⩽ 1,5	18	42
⩽ 2	21	45
⩽ 3	27	51
⩽ 4	34	58
⩽ 5	39	63

Dimensions in millimetres



Key

$h_L = 42 + (r_1 \text{ or } r_2)$

$l_g = t_1 + t_2 + r_1 + r_2 + 6$ (in millimetres)

NOTE See Clause 4.

Figure 7 — Flat multi-spot peel specimen

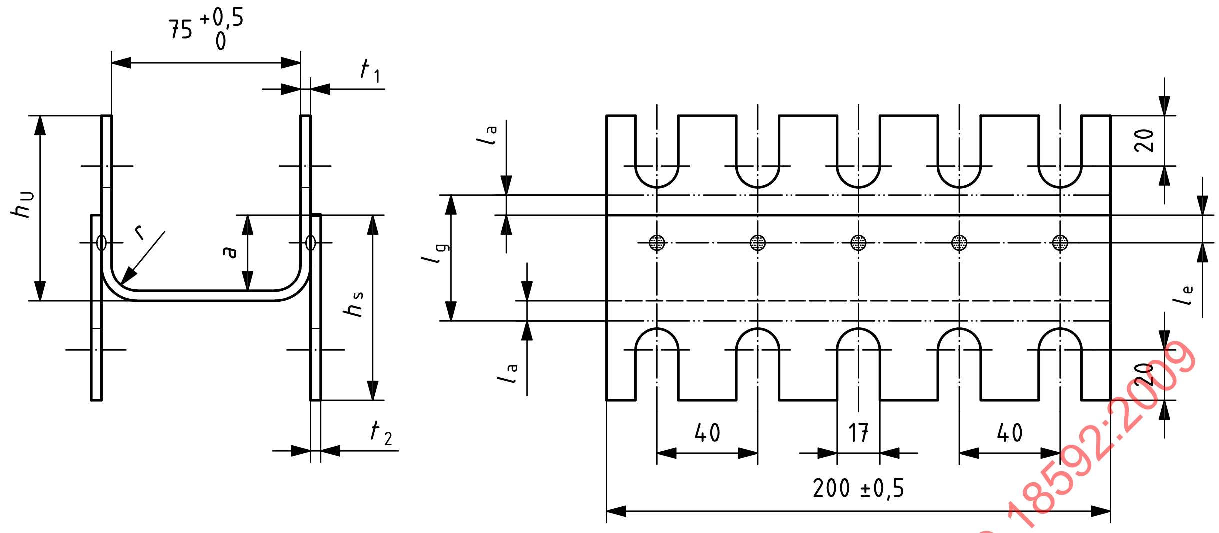
Table 4 — Dimensions of flat multi-spot peel specimen

Dimensions in millimetres

Smallest sheet thickness t_1 or t_2	Overlap a	Edge distance l_e	Radius r_1 or r_2 [a]
1	16	7	$2 < r < 3$
1,5	18	7,5	$3 < r < 4,5$
2	21	8,5	$4 < r < 6$
3	27	11	$6 < r < 9$
4	34	14	$8 < r < 12$
5	36,5	15	$10 < r < 15$

[a] The bending radius for AHS steels may have to be increased. In this case, modifications of overlap and other dimensions may be necessary.

Dimensions in millimetres



Key

$l_g = (2\,l_a + a + t_1)$

$h_s = a + l_a + 36 + t_1$ (in millimetres)

$h_U = 42 + (r_1 \text{ or } r_2)$

NOTE See Clause 4.

Figure 8 — H-Shear specimen

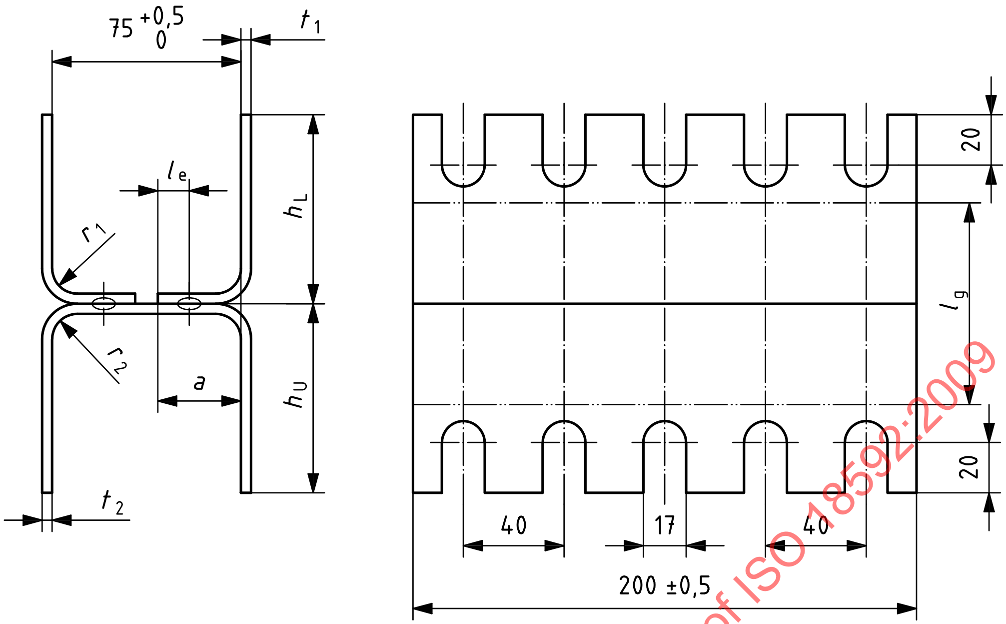
Table 5 — Dimensions of shear multi-spot H-specimens

Dimensions in millimetres

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

[a] The bending radius for AHS steels may have to be increased. In this case, modifications of overlap and other dimensions may be necessary.

Dimensions in millimetres



Key

h_L = 42 + (r_1 or r_2)

h_U = 42 + (r_1 or r_2)

NOTE See Clause 4.

Figure 9 — H-peel specimen

Table 6 — Dimensions of double-disc 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]
1	16	7	$2 < r < 3$
1,5	18	7,5	$3 < r < 4,5$
2	21	8,5	$4 < r < 6$
3	27	11	$6 < r < 9$

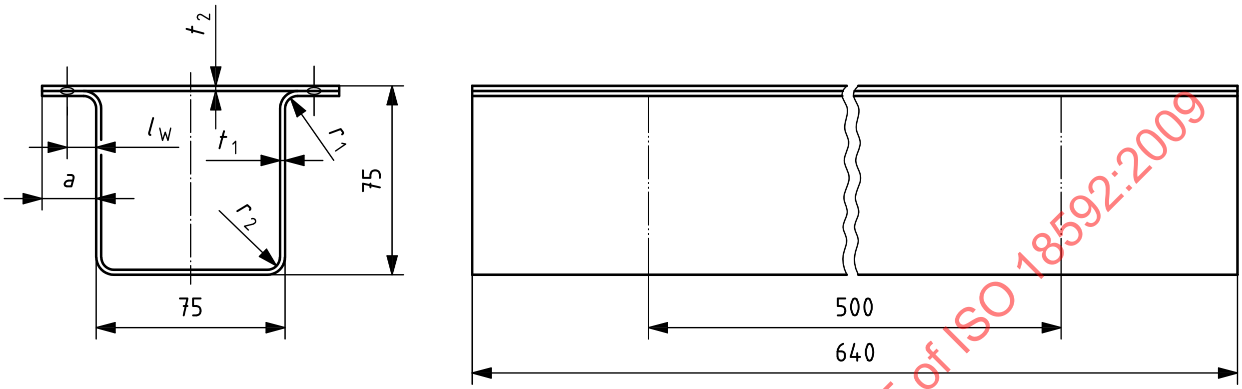
[a] The bending radius for AHS steels may have to be increased. In this case, modifications of overlap and other dimensions may be necessary.

5.4.3 Geometry of the hat and closed section specimens

The hat specimens allow, under 3-point bending, the investigation of the structural behaviour of the specimens under different types of loading. An investigation of the load-carrying behaviour of the welds is not possible because these are subjected to undefined, non-uniform loads. The specimens are relatively difficult to manufacture and to test. The difficulty in manufacturing 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 welds in the axis of the weld line.

The same applies to the double disc specimen which requires special deep drawing tools for each sheet thickness. This specimen allows the investigation of defined complex load combinations (shear and peel loads).

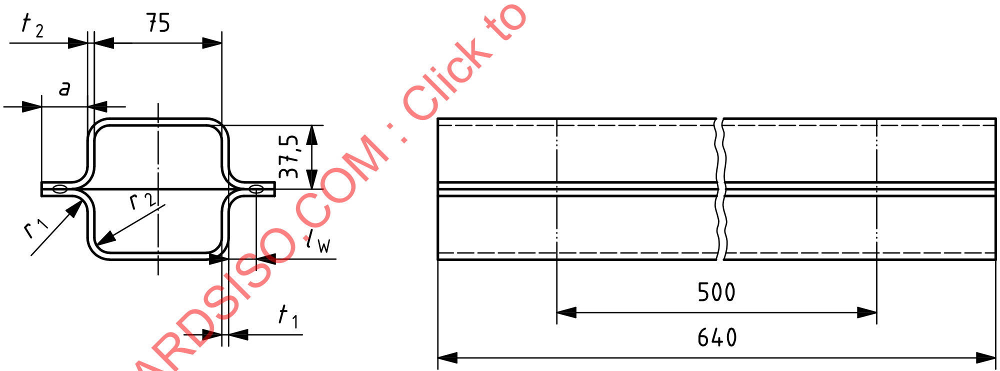
Dimensions in millimetres



NOTE See Clause 4.

Figure 10 — Single-hat specimen

Dimensions in millimetres



NOTE See Clause 4.

Figure 11 — Double hat specimen

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

Dimensions in millimetres

Smallest sheet thickness t_1 or t_2	Distance from wall l_w	Overlap a	Radius r_1 or r_2 [a]
⩽ 1	9	16	$2 < r < 4$
⩽ 1,5	9	18	$3 < r < 4{,}5$
⩽ 2	11,5	21,5	$4 < r < 6$
⩽ 2,5	12	25	$5 < r < 7$
⩽ 3	12	27	$6 < r < 8$
⩽ 4	12	27	$8 < r < 10$

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

[a] The bending radius for AHS steels may have to be increased. In this case, modifications of overlap and other dimensions may be necessary.

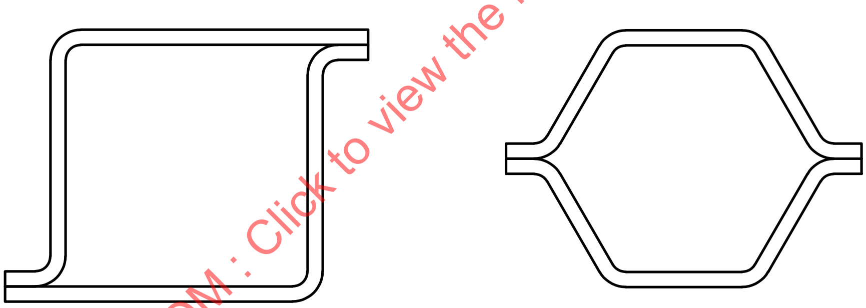


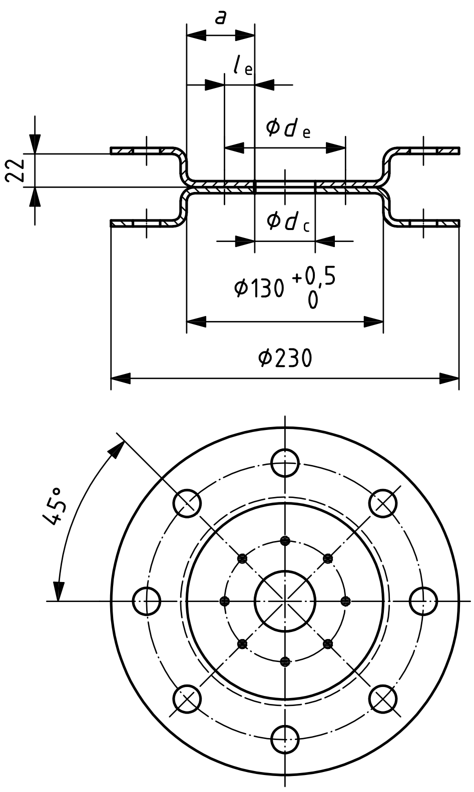
Figure 12 — Various closed sections

5.4.4 Double disc and KS-2 specimen

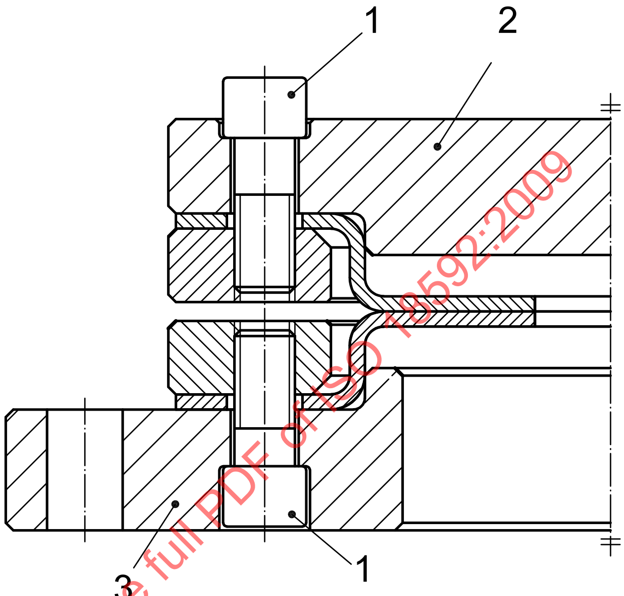
The dimensions of the double disc specimen are given in Figure 13. These are valid for all thicknesses up to 3,0 mm. The number of welds shall be distributed uniformly over the circumference of the pitch circle, resulting in a uniform pitch. The diameter of the central hole depends on the sheet thickness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

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

Dimensions in millimetres



a) **Dimensions**



b) **Clamping device**

Key

1 clamping bolts

2 upper clamping plate

3 base clamping plate

NOTE See Clause 4.

Figure 13 — Double disc peel and shear specimen

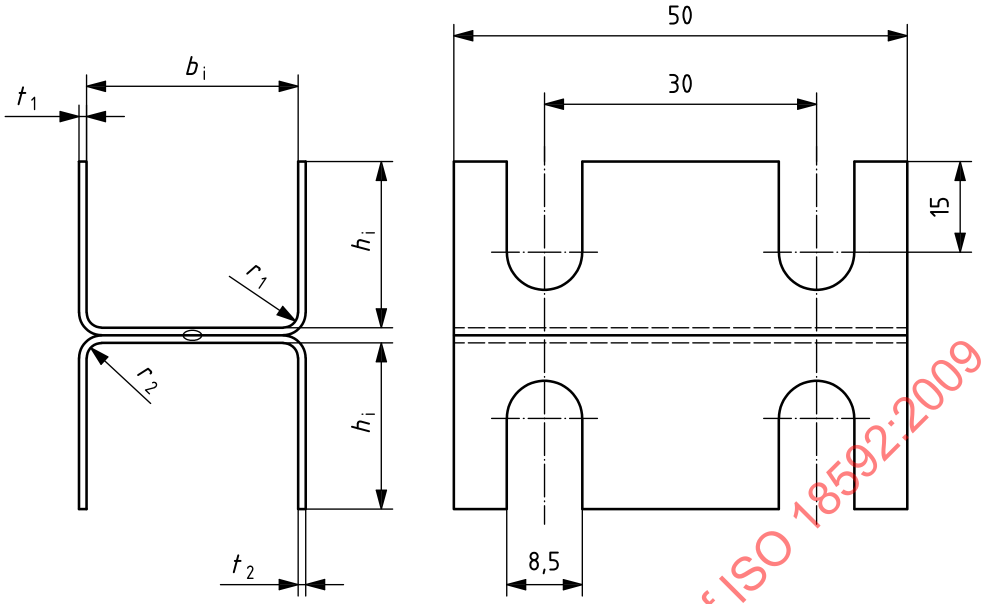
Table 8 — Dimensions of flat multi-spot peel specimen

Dimensions in millimetres

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

[a] The deep drawing radius for AHS steels and some aluminium and magnesium alloys may have to be increased. In this case, modifications of overlap and other dimensions may be necessary.

Dimensions in millimetres



NOTE See Clause 4.

Figure 14 — KS-2 specimen

Table 9 — Dimensions KS-2 specimen

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	Inner height h_i
0,8 to 1,5	2	4	$22^{+0,5}_{0}$	20
1,6 to 2,5	4	8	$26^{+0,5}_{0}$	26
2,6 to 3,5	6	10	$30^{+0,5}_{0}$	28
3,6 to 4,0	8	12	$34^{+0,5}_{0}$	30
4,0 to 5,0	10	15	$36^{+0,5}_{0}$	33

[a] The maximum bending radius, $r_{i,max}$, for AHS steels may have to be increased. In this case, modifications of inner height and position of hole centre for the slits may be necessary.

6 Requirements for testing machine

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

The tests may be performed as load controlled tests in any of the following types of fatigue testing machines:

a) mechanical (eccentric crank, power screws, rotating masses);

b) electromechanical or magnetically driven;

c) hydraulic or electro-hydraulic.

The machine shall 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 grips, see Clause 7, are relatively heavy, the testing machine shall be calibrated dynamically to eliminate the effect of mass forces. This is of utmost importance at higher testing frequencies, e.g. on resonance testing machines.

7 Specimen grips and alignment

7.1 General

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

7.1.1 Alignment verification

The alignment of the grips — axial and transversal — shall be verified in order to ensure that the specimens are not twisted or deformed in any manner.

In order to ensure uniform load distribution, the co-axial alignment of the upper and lower grips, and their parallel alignment shall be verified.

7.1.2 Clamping device calibration

A calibration specimen, Annex A, should be used to verify the uniformity of the loading over the length of the specimen. The verification shall be carried out in the same position as the tests. The magnitude of the strains, ε, at different positions on the calibration specimen shall be measured using the applied strain gauges.

The calibration should also be verified at 90° and 180° rotation of the grips to ensure symmetry between the upper and lower grips.

If the tests are to be carried out with modified grips, the specified non-uniform loading shall also be verified with the same calibration specimen (Reference [6]).

NOTE Design, material and manufacturing procedure of the calibration specimen are given in Reference [6].

The non-uniform loading, ΔP, expressed as a percentage, is defined as:

$$\Delta P = \frac{\varepsilon_{\mathrm{max}} - \varepsilon_{\mathrm{m}}}{\varepsilon_{\mathrm{m}}} \times 100\ \% \quad (1)$$

where

$\varepsilon_{\mathrm{max}}$ is the maximum strain measured on the specimen;

ε_{m} is the average strain measured on the specimen.

The maximum non-uniform loading as defined by Equation (1) shall not exceed 2 % for any given varying load.

7.2 Shear and peel loading

7.2.1 General

A set of standard grips, upper and lower part, has been designed such that a uniform load distribution in all welds is ensured. The grips were originally designed for test specimens made of conventional high strength steels with a sheet thicknesses between 0,5 mm and 3,0 mm. For specimens with a sheet thickness greater than 5 mm and for steels with which the bending radii are greater than those given in the tables, the overlap requires modification, see Tables 2 and 3. For aluminium specimens, material up to a thickness of 5,0 mm may be used. The grips are shown in Annexes B and C. It is of the utmost importance to manufacture the grips in accordance with the given tolerances to ensure optimum loading conditions.

The flat multi-spot shear and peel specimens should be tested pair-wise using the grips for the H-specimens.

The load should be transmitted from the testing machine through the grips to the specimen through the clamping force between the specimen and the grips. To ensure that no slippage occurs, the nuts (M16) shall be tightened to the prescribed torque, 150 Nm. Molybdenum(IV) sulfide should be applied to the threads and hardened washers should be used to minimize friction.

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

Take precautions 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 testing of thicker gauge specimens and joints with higher strengths. As an alternative, a hydraulic clamping device can be used instead of screws, see Annex B. The hydraulic pressure required depends on the diameter of the cylinders.

7.2.2 Shear loading

One grip is 75 mm thick, for fixing the U-bend part. For the opposite part of the specimen, the grip is 63 mm thick. Mount spacers on both sides of the 63 mm thick grip to compensate for the sheet thickness, i.e. the spacer shall have a thickness of $(6 + t)$ mm where t is the sheet thickness (assuming that the sheet in the U-bend 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”. Thicker spacers shall be serrated on both sides to prevent slippage.

7.2.3 Peel loading

Similar to 7.2.2, both the upper and the lower grips are 75 mm wide.

7.2.4 Shear loading parallel to the joint line

Test fixture for shear loading parallel to the joint line: testing equipment for 4-point bending according to the state of the art is recommended for testing the different closed hat sections.

7.2.5 Torsion loading

The load distribution in the spot welds of closed cross-sections subjected to torsion loading 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 spot welds.

8 Test procedure

8.1 General

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

8.2 Mounting the H-specimens

The specimens shall be clamped such that there is no twist, misalignment or axial displacement, see also 8.3. A pre-requisite for this is the alignment of the grips before any tests are carried out.

8.3 Clamping procedure for the H-specimens

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

— 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 gripping heads, respectively. The spacers shall be placed on both sides of the gripping head. The spacers shall not be in contact with the specimen in the bend radius. 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.

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

8.4 Fatigue test

8.4.1 General

The test shall be carried out at 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 shall be positive.

Care shall be taken not to overload the specimen at the initiation 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 (see EN 10130[4]) shall be maintained at all times to within 1 % of the pre-set value (peak loads).

8.4.2 Test frequency

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

No thermal effect of test frequency has been detected for spot welded specimens at frequencies up to 80 Hz (Reference [6]). When testing specimens where visco-elastic materials are involved, e.g. adhesives, the thermal effects can have a large negative influence on the fatigue life. Therefore, tests shall be performed to verify the effect of test frequency on bonded specimens.

8.5 Test termination

8.5.1 General

The test shall be terminated when the specified failure criterion is fulfilled. The failure criterion is based on the loss of integrity of the specimen and is noticeable as a loss of stiffness. 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.

8.5.2 Stiffness calculation

The stiffness, c, is calculated as:

$$c = \frac{\Delta F}{\Delta L}$$

where

ΔF is the load range ($F_{max} - F_{min}$);

ΔL is the displacement ($L_{max} - L_{min}$).

It is assumed that a linear relationship exists between displacement and load, since it is assumed that the test is to be carried out in the elastic range.

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

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

The failure criterion is based on a relative loss of stiffness. The displacement can thus be measured either directly on the specimen or as a relative displacement of the grips.

As a reference (100 % stiffness), the stabilized stiffness value should be used. Stabilization usually occurs relatively soon after the start of the test, see Figure 15.

8.5.3 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 shall 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, according to 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 could be stored for later analysis.

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

8.5.4 Failure criterion and number of cycles to failure

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

$$\frac{c - c_0}{c_0} = -28{,}6\ \% \quad \text{or} \quad \frac{c - c_0}{c_0} = -40\ \%$$

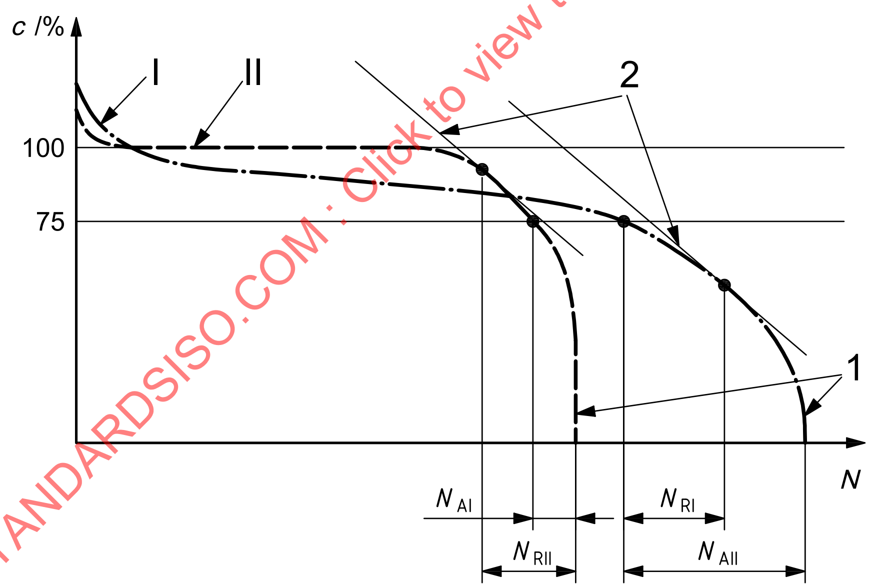
the number of cycles to failure corresponds to a specimen displacement of

$$\frac{\Delta L - \Delta L_0}{\Delta L_0} = 40\ \% \quad \text{or} \quad \frac{\Delta L - \Delta L_0}{\Delta L_0} = 67\ \%$$

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 decreased 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 shall be agreed upon after consultation with the relevant design department before the test is conducted.

The failure criterion to be used depends, for example, on the application. In the aircraft and space 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 shall be correlated to the relevant failure criterion. For spot welds in steel, a visible crack length equal to the diameter of the weld results in a stiffness loss of about 40 %.

The reason for introducing a new parameter, the rate of integrity loss (stiffness) for the failure criterion is shown in Figure 15. Two specimens exhibiting an identical relative decrease in stiffness can have a great difference in their residual lives. In Figure 15, 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, rate of 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 $\frac{d^2 c}{dN^2}$, i.e. rate of stiffness loss (N = number of load cycles, c = relative stiffness)

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

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

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

Figure 15 — Fatigue life using absolute stiffness loss, relative stiffness loss and rate of stiffness loss as failure criteria

9 Test report

9.1 Basic information

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 test procedure used to generate the data. The presentation of fatigue test results shall 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.

9.1.1 Material prior to fatigue test specimen preparation

The minimum information to be presented shall include the designation or specification of the material (e.g. EN 10130 [4] DC06), nominal thickness and the chemical analysis.

9.1.2 Mechanical properties

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

9.1.3 Specimen design and preparation

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

9.1.4 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 [4], EN 10346 [5], and ASTM E468 [2].

9.1.5 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 of testing machines used shall be given.

One test series, that means that all specimens whose results are for the same Wöhler curve, shall be tested with the same equipment.

9.1.6 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.

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

9.1.7 Results of post-test examination

For each test specimen, the reason for ending the test, either achievement of the failure criterion or run-out, and, if applicable, a description of the appearance of the failure surface and the location of the crack initiation should be given.

9.2 Presentation of fatigue test results

9.2.1 Tabular presentation

The fatigue test results shall 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 ending the test;

f) results of the post-test examination (see 9.1.7).

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

9.2.2 Graphical presentation

The fatigue test data may be presented graphically as an F-N (load-life) curve. 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 or kilonewtons, is plotted on the ordinate. A line is fitted by regression analysis to the fatigue data or approximated by eye. If data are fitted by regression analysis, the equation of the load-life and the corresponding statistical scatter should be presented.

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

9.2.3 Numerical evaluation, statistics

In the derivation of the analytical expression for describing the load amplitude, F_a, vs load cycles, N, curve the number of load cycles is the dependent variable and the load amplitude the independent variable.

With this a simple linear regression model can be constructed for determining the mean curve (ASTM E468 [2]):

$$\log N = \log A_1 + A_2 \log F_a \quad (2)$$

where

$\log A_1$ is the intersection of the line of best fit with the ordinate;

A_2 is the k value or gradient of the line of best fit.

Several different techniques may be employed for optimizing the coefficients in Equation (2). The use of the sum of least squares regression, a technique widely used in technical fields, is recommended.

The distribution of fatigue lives about the mean curve is generally unknown. The distribution of fatigue lives at a given load level is in many cases well modelled by log-normal distribution; that is, the distribution of log N values at a given load value tends to follow a normal distribution. When analysing fatigue data, the residuals in log N should be examined to determine the quality of fit and the uniformity of the scatter. A residual is the deviation of an individual point from the fitted curve, i.e. predicted minus the observed fatigue life.

NOTE More information about fatigue data analysis can be found in ASTM E468 [2] and ASTM E1942 [3].