
**Fatigue — Fatigue testing of welded
components — Guidance**

*Fatigue — Essais de fatigue sur composants soudés — Lignes
directrices*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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/TR 14345 was prepared by the International Institute of Welding, which has been approved as an international standardizing body in the field of welding by the ISO Council.

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Requests for official interpretations of any aspect of this part of ISO/TR 14345 should be directed to the ISO Central Secretariat, who will forward them to the IIW Secretariat for an official response.

Introduction

Fatigue tests of welded specimens are the basis of all the main fatigue design codes and standards for welded components and structures. However, inevitably these are not fully comprehensive and there is a constant need for new data to extend them. Recognizing this, there is a growing tendency to allow the user to deviate from the rules by performing special fatigue tests to validate a design. This Technical Report addresses both these situations by providing guidance on the production of welded test specimens and their fatigue testing for producing data either for general application or to validate a specific design.

Welded metallic structures can be large and complex, incorporating many weld details and structural configurations. Furthermore, the loading that they are required to withstand in service can also be complex. Therefore, the scope for performing fatigue tests on full-scale welded structures under truly representative loading conditions is very limited, and usually expensive. Consequently, for both technical and economic reasons, it is rarely attempted. Instead, in many circumstances, it is sufficient to isolate individual weld details and incorporate them in small-scale specimens to test them. An important condition is that the resulting specimens should be realistic in terms of features in real structures that affect fatigue strength, such as material type, section thickness, plate preparation, weld type and welding conditions, residual stresses and the nature of the fatigue loading. This Technical Report provides guidance on the production and fatigue testing of specimens representing weld details. Reference is made to other IIW guidance on the fatigue testing of large-scale specimens representing sub-assemblies or structural components (Reference [1]); more detailed guidance on the loading required for variable-amplitude testing is given in Reference [2] and the statistical evaluation of fatigue data in Reference [3].

By its nature, this Technical Report covers two distinct disciplines, welding and mechanical testing. If reliable fatigue data are to be obtained, both need to be truly representative of practical conditions. Thus, the laboratory test specimens need to duplicate actual welded structures and the test conditions need to duplicate real-life loading and operating conditions. Apart from the provision of design data, use of the recommendations in this Technical Report is intended to facilitate comparison of fatigue test data and avoid biased statistics if results obtained from different sources are combined.

Use of this Technical Report is intended to allow, on the one hand, more adequate comparison of the results from different origins (e.g. same welded joint but from another workshop or testing laboratory) and, on the other hand, the plotting of more reliable fatigue curves for design purposes.

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Fatigue — Fatigue testing of welded components — Guidance

1 Scope

This Technical Report gives guidance on best practice for fatigue testing under constant- or variable-amplitude loading of welded components in the medium- and high-cycle regimes, corresponding to applied loading that results in nominal stresses that do not exceed yield. Low-cycle fatigue testing under strain control is not specifically covered, although the same test specimens can be suitable for either low- or high-cycle fatigue testing. The different steps involved in the manufacture and preparation of the welded specimens and the final presentation and evaluation of the test results are also covered.

This Technical Report does not cover corrosion or high-temperature fatigue testing.

2 Terms and definitions

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

2.1 failure criterion

specimen damage chosen for ending the test

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2.2 flank angle

θ

contact angle between the weld face and the plate at the weld toe

2.3 irregularity factor

I

ratio of the number of mean crossings, N_0 , with positive slope to number of peaks or valleys in the given load history, N_p

$$I = \frac{N_0}{N_p}$$

NOTE See Figure 1.

2.4 Maxima

2.4.1 maximum load range

ΔF_{\max}

maximum load range encountered in a variable-amplitude applied load spectrum

2.4.2 maximum stress range

$\Delta \sigma_{\max}$

maximum stress range encountered in a variable-amplitude applied stress spectrum

2.5
number of cycles to failure

N_f
number of cycles when the failure criterion is reached

2.6
peak factor

ratio of the maximum value attained in the applied load (or stress) history to the mean load (or stress)

2.7
range

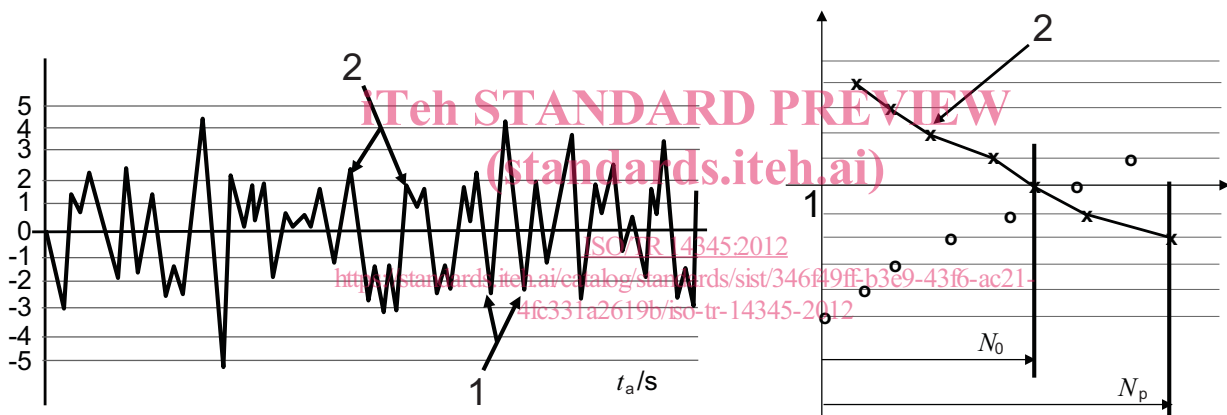
algebraic difference between the maximum and minimum values of a quantity under cyclic loading

2.8
standard deviation

positive square root of the mean of the squared deviations of a variable from its arithmetic mean

2.9
weld toe radius

ρ
contact radius between the weld toe and the plate



a) Random signal: load levels versus time

b) Counting for irregularity factor definition: load level versus number of peaks

Key

- 1 negative peaks
- 2 positive peaks
- t_a time

Key

- 1 mean level
- 2 number of level crossings up
- N_0 number of mean crossings
- N_p number of peaks or valleys in the given load history
- × cumulative distribution of peaks
- cumulative distribution of valleys

Figure 1 — Random signal and counting for irregularity factor definition

3 Symbols and abbreviated terms

See Table 1.

Table 1 — Symbols and abbreviated terms

Symbol	Quantity	Designation
a, b, d	Length	Dimensions used to calculate misalignment parameters
ΔF	Force	Load range
ΔF_{\max}	Force	Maximum load range in the spectrum
$\Delta\sigma_{\text{nom}}$	Stress	Nominal stress range
$\Delta\sigma$ (or S)	Stress	Stress range
$\Delta\sigma_{\text{m}}$	Stress	Membrane stress range
$\Delta\sigma_{\text{S}}$	Stress	Secondary bending stress range
$\Delta\sigma_{\max}$	Stress	Maximum stress range in the spectrum
$\Delta\sigma_{\text{D}}$	Stress	Fatigue limit for parent material
$\Delta\sigma_{\text{cor}}$	Stress	Corrected stress range including secondary bending stress due to misalignment
$\Delta\sigma_{\text{shs}}$	Stress	Structural hot-spot stress range
$\Delta\varepsilon$	Length/length or %	Strain range
e	Length	Axial misalignment
ϕ	Radians	Angular distortion
h	Length	Weld leg length
I	—	Irregularity factor, N_0/N_p
L	Length	Distance over which misalignment extends
l	Length	Distance from weld toe to radius measuring circle
λ	Dimensionless	Correction factor dependent on restraint on misaligned cruciform joints
N_f	Cycles	Number of cycles to failure
N_0	—	Number of mean crossings with positive slope in spectrum loading sequence
N_p	—	Number of peaks or valleys in spectrum loading sequence
R	—	Stress ratio, S_{\min}/S_{\max}
ρ	Length	weld toe radius
S_{\min}, S_{\max}	Stress	Minimum and maximum (algebraic) applied stress (tension positive, compression negative)
S_N	Stress	Fatigue strength at life N cycles
s (or Stdv)	—	Standard deviation
$s_{\log N}$	—	Standard deviation of $\log N$
$s_{\log S}$	—	Standard deviation of $\log S$
s_S	Stress	Standard deviation of S_N
σ_{m}	Stress	Membrane stress
σ_{S}	Stress	Secondary bending stress
t	Length	Plate thickness
θ	Degrees	Weld toe flank angle

4 Specimen design and manufacture

4.1 Specimen design

4.1.1 General

The specimen design depends on the objectives of the tests, together with any practical limitations such as the available type of fatigue-testing equipment, material and time. If the specimen is intended to model a welded joint in an actual structure, it shall be as representative as possible of that joint in terms of material, weld detail, geometry, dimensions, and manufacturing quality. In addition, the specimen design should take account of how loads are applied to the test section to ensure consistency with the original structural element. A relevant example to illustrate this point is given in Reference [4].

If it is required to produce several nominally identical specimens, e.g. to produce an $S-N$ curve, a suitable technique is to extract them from larger panels, as shown in Figure 2. Normally, extension pieces are welded at each end to allow the test weld to traverse the entire width of the panel. These are then removed and the resulting edges ground smooth. Similarly, several strip specimens can be extracted from a single butt or fillet welded girth joint between two tubes. However, these approaches can only be used if the weld detail is a continuous weld oriented transverse to the direction of fatigue loading. In other cases, such as those shown in Figure 3, each specimen shall be fabricated individually.

An important feature of welded structures is the nature of the residual stresses due to welding and subsequent manufacturing operations. In most cases, these can be very high, up to yield, and tensile. Their effect under fatigue loading is the same as that of an applied high tensile mean stress. Most fatigue design rules provide design data that include the effect of such tensile residual stress. However, small-scale welded specimens are unlikely to embody high residual stresses from welding. One option with steel specimens is to induce them by spot heating (Reference [5]), or their effect can usually be simulated by the choice of loading (see 6.3).

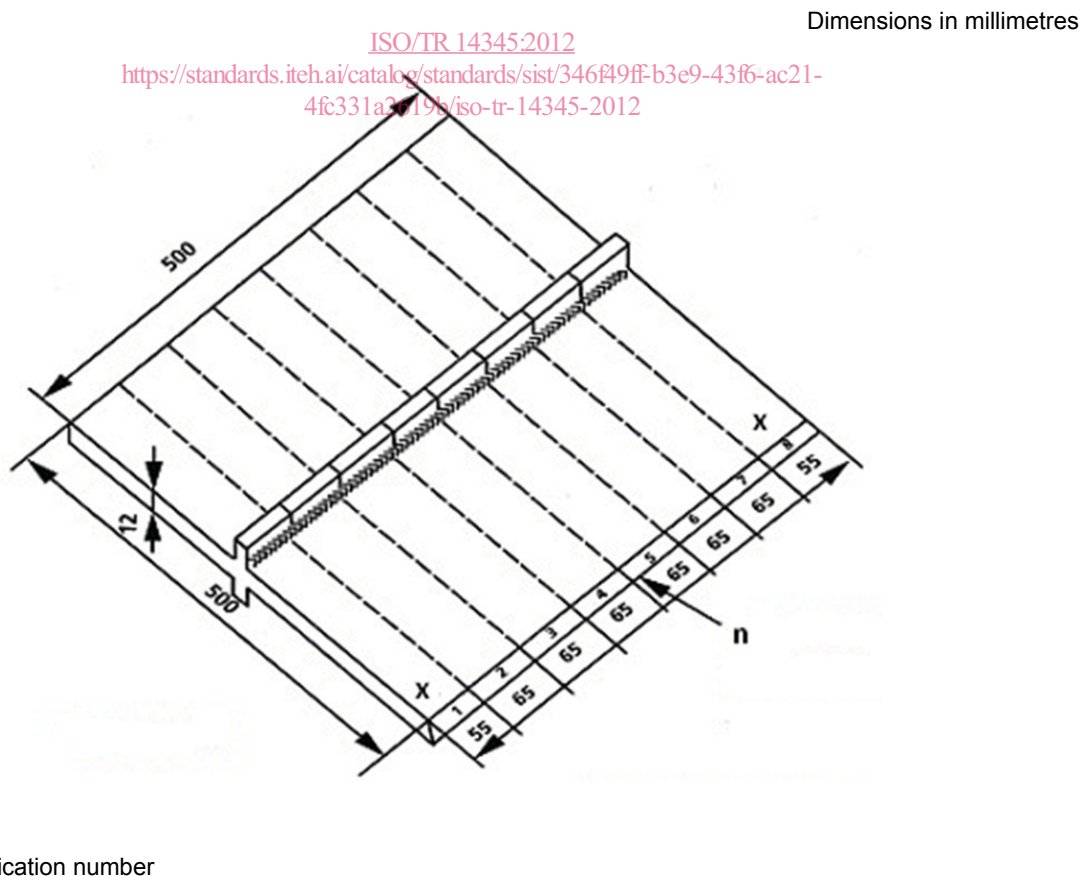


Figure 2 — Example of a welded panel and the extraction of narrower fatigue test specimens

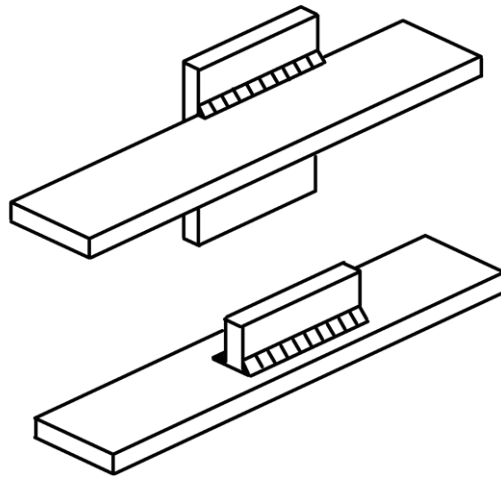


Figure 3 — Examples of fatigue test specimens that would need to be made individually

4.1.2 Influence of method of loading

Care is needed to ensure that fatigue failure of the test specimen occurs at the weld detail of interest, rather than prematurely at some location associated with the method of testing. In this respect, there is always the risk that axially loaded plate specimens gripped in wedge jaws fail in that region as a result of the notching effect of the jaws if they indent the specimen. This problem is particularly acute if the weld detail is one with relatively high fatigue strength. It can usually be avoided by the use of waisted specimens that are narrower in the test section than where they are gripped. Similarly, specimens loaded in bending can fail at the load points if they indent the specimen or the local shear stress in the specimen is too high. General recommendations on the dimensions of fatigue test specimens are given in Figure 4.

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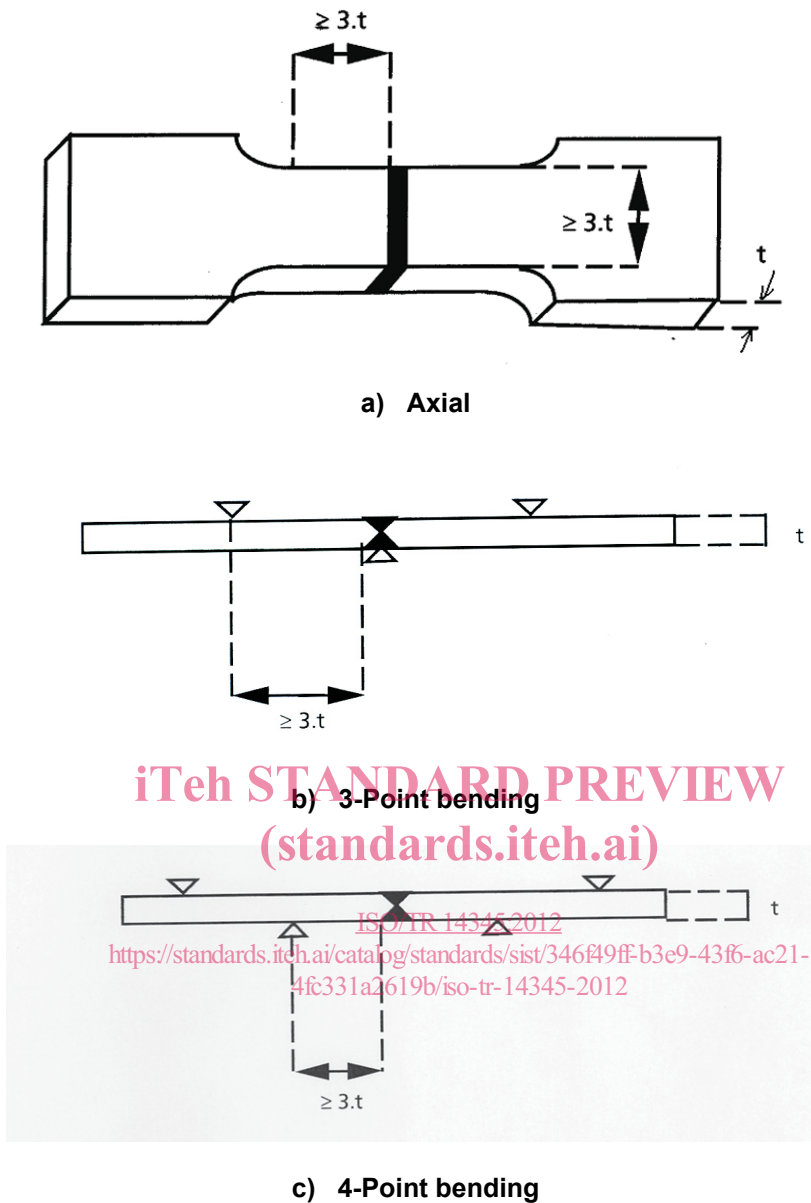


Figure 4 — Geometrical characteristics of welded specimens loaded in tension or bending

4.2 Manufacture of test specimens

4.2.1 Material

The test specimens should be manufactured from material of the same specification, form, and thickness as that used for the component or structure that the specimen is intended to represent. Since the fatigue performance of some welded joints is effectively independent of material tensile strength, some flexibility is possible on the choice of material grade. Similarly, some tolerance on material form and thickness may be possible. Any such deviations should be justified and recorded.

4.2.2 Welding procedure

The welding operation should conform to those performed on components or structures of the type and material that the specimen is intended to represent, in compliance with recognized codes. Panels used to produce several small-scale specimens (Figure 2) should be assembled so as to maintain the thermal

conditions and disposition of the welds in the real structure. When relevant, the rolling direction of a plate should be the same as that in the original structure.

To simulate practical conditions, it is prudent to include weld runs containing start-stops.

If the tests are being performed to validate a particular component or structure, each type of welded joint should be accurately characterized in terms of relevant dimensions and parameters. For example, in the case of arc welding, the following characteristics may be relevant:

- plate thickness;
- base metal type;
- rolling direction;
- welding process;
- shielding gas type, if any;
- welding position (flat, overhead, etc.);
- travel speed;
- preheat temperature;
- post-weld heat treatment, if any;
- electrical parameters of the welding process;
- size and shape of the welds;
- type and diameter of the electrodes;
- sequence of the different passes;
- locations of any start-stop positions.

Additionally, it is helpful to mark locations where the characteristics of the weld may have changed, e.g. due to a change in welding position or direction, or at a repair.

Unless it is a feature of the test, care should be taken to ensure that the finished weld is not cleaned by wire brushing or shot blasting or coated with oil or grease, since such treatments are likely to influence the fatigue performance of the welded specimen.

4.2.3 Joint alignment

Welded joints, particularly butt and cruciform joints, are highly susceptible to misalignment, arising mainly from distortion during welding, variations in section shape or thickness and practical difficulties of achieving perfect alignment during assembly. The two general types of misalignment are axial, due to a mismatch of the centrelines of abutting parts, and angular, usually due to distortion, as illustrated in Figure 5. Misalignment can affect the fatigue performance of the welded specimen in that it may influence the weld profile (Reference [6]) or, as shown in Figure 5, because it leads to the introduction of secondary bending stress when the joint is loaded (Reference [7]). Thus, care is needed to ensure that any misalignment in the specimen is representative of that in the actual structure and, ideally, that its effect as a source of secondary stress is quantified (see 5.3.3).