भारतीय मानक
Indian Standard

IS 15728 : 2022
ISO 15620 : 2019

वेल्डिंग — धात्विक सामग्री की घर्षण वेल्डिंग

(पहला पुनरीक्षण)

Welding — Friction Welding of Metallic Materials

(First Revision)

ICS 25.160.10

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Welding General and its Application Sectional Committee, MTD 11

NATIONAL FOREWORD

This Indian standard which is identical to ISO 15620 : 2019 ‘Welding — Friction welding of metallic materials (*first revision*)’ issued by the International Organization for Standardization (ISO), was adopted by the Bureau of Indian Standards on the recommendation of the Welding General and its Applications Sectional Committee and approval of the Metallurgical Engineering Division Council.

This standard was originally published in 2006 adopting ISO 15620 : 2000 ‘Welding — Friction Welding of Metallic Material’ under dual numbering system. The first revision of this standard has been undertaken to align it with the latest version of ISO 15620 : 2019.

The changes compared to the previous edition are as follows:

a) Clause **2** has been updated ;
b) In Clause **3**, terms not used in the text have been deleted;
c) In Annex B of **4** processes based on friction have been added;
d) The recommended text to perform on test weld has been clarified (addition of Table 4)

The text of ISO standard has been approved as suitable for publication as an Indian Standard without deviations. Certain terminologies and conventions are, however, not identical with those used in Indian Standard. Attention is especially drawn to the following:

a) Wherever the words `International Standard’ appear referring to this standard, itshould be read as `Indian Standard’
b) Comma (,) has been used as a decimal marker while in Indian Standards the currentpractice is to use a point (.) as the decimal marker.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis shall he rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Contents

Page

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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 10, *Quality management in the field of welding*.

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 10 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.

This second edition cancels and replaces the first edition (ISO 15620:2000), which has been technically revised.

The main changes compared to the previous edition are as follows:

— Clause 2 has been updated;

— in Clause 3, terms not used in the text have been deleted;

— in Annex B of 4 processes based on friction have been added;

— the recommended test to perform on test weld has been clarified (addition of Table 4).

Introduction

Friction welding is a method for making welds in the solid phase in which one component is moved relative to and in pressure contact with the mating component to produce heat at the faying surfaces, the weld being completed by the application of a force during or after the cessation of relative motion. There are several forms of supplying energy and various forms of relative movements.

The generation of friction heating results in a comparatively low joining temperature at the interface. This is largely the reason why friction welding is suitable for materials and material combinations which are otherwise difficult to weld. The weld region is generally narrow and normally has a refined microstructure.

While the friction welding process deals primarily with components of circular cross-section it does not preclude the joining of other component shapes.

Indian Standard

WELDING — FRICTION WELDING OF METALLIC MATERIALS

1 Scope

This document specifies requirements for the friction welding of components manufactured from metals.

It specifies requirements particular to rotational friction welding related to welding knowledge, quality requirements, welding procedure specification, welding procedure approval and welding personnel.

This document is appropriate where a contract, an application standard or a regulatory requirement requires the demonstration of the manufacturer's capability to produce welded constructions of a specified quality. It has been prepared in a comprehensive manner to be used as a reference in contracts. The requirements given can be adopted in full or some can be deleted, if not relevant to the construction concerned.

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 database 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
axial force
force in axial direction between components to be welded

3.2
burn-off length
loss of length during the friction phase

3.3
burn-off rate
rate of shortening of the *components* (3.4) during the friction welding process

3.4
component
single item before welding

3.5
component induced braking
reduction in *rotational speed* (3.18) resulting from friction between the interfaces

3.6
external braking
braking located externally reducing the *rotational speed* (3.18)

3.7
faying surface
surface of one *component* (3.4) that is to be in contact with a surface of another *component* (3.4) to form a joint

3.8
forge force
force applied normal to the *faying surfaces* (3.7) at the time when relative movement between the *components* (3.4) is ceasing or has ceased

3.9
forge burn-off length
amount by which the overall length of the *components* (3.4) is reduced during the application of the *forge force* (3.8)

3.10
forge phase
interval time in the friction welding cycle between the start and finish of application of the *forge force* (3.8)

3.11
forge pressure
pressure (force per unit area) on the *faying surfaces* (3.7) resulting from the axial *forge force* (3.8)

3.12
forge time
time for which the *forge force* (3.8) is applied to the *components* (3.4)

3.13
friction force
force applied perpendicularly to the *faying surfaces* (3.7) during the time that there is relative movement between the *components* (3.4)

3.14
friction phase
interval time in the friction welding cycle in which the heat necessary for making a weld is generated by relative motion and the *friction force(s)* (3.13) between the *components* (3.4), i.e. from contact of *components* (3.4) to the start of deceleration

3.15
friction pressure
pressure (force per unit area) on the *faying surfaces* (3.7) resulting from the axial friction force

3.16
friction time
time during which relative movement between the *components* (3.4) takes place at *rotational speed* (3.18) and under application of the *friction force(s)* (3.13)

3.17
interface
contact area developed between the *faying surfaces* (3.7) after completion of the welding operation

3.18
rotational speed
number of revolutions per minute of rotating *component* (3.4)

3.19
stick-out
distance a *component* (3.4) sticks out from the fixture, or chuck in the direction of the mating *component* (3.4)

3.20
deceleration phase
interval in the friction welding cycle in which the relative motion of the *components* (3.4) is decelerated to zero

3.21
deceleration time
time required by the moving *component* (3.4) to decelerate from friction speed to zero speed

3.22
total length loss (upset)
loss of length that occurs as a result of friction welding, i.e. the sum of the *burn-off length* (3.2) and the *forge burn-off length* (3.9)

3.23
total weld time
time elapsed between *component* (3.4) contact and end of forging phase

3.24
welding cycle
succession of operations carried out by the machine to make a weldment and return to the initial position, excluding *component* (3.4) - handling operations

3.25
weldment
two or more components joined by welding

4 Welding knowledge

4.1 Process

4.1.1 General

The classification of friction welding processes is listed in Table 1.

Table 1 — Classification of friction welding processes

Friction welding

Relative motion classification | **Energy classification**

Energy classification

Continuous drive

The process variant where power or energy is provided by an infinite duration source and maintained for a preset period

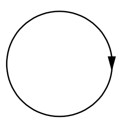
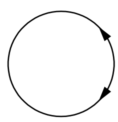
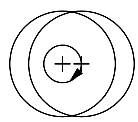
Stored energy

The process variant where the energy for welding is supplied by the kinetic energy stored in a rotating system or fluid storage system

Hybrid system

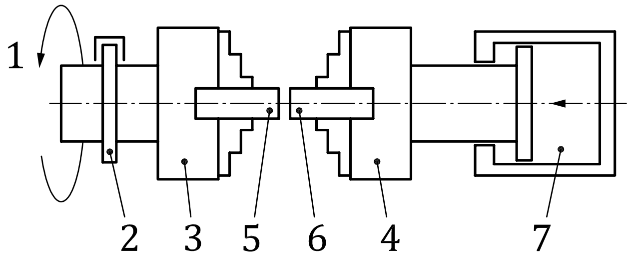
Combining some features of both methods

Relative motion classification

Rotational	**Linear reciprocation**	**Angular oscillation**	**Orbital**
A method in which one component is rotated relative to and in contact with the mating face of another component or components.	A method in which one component is moved in a linear oscillating motion relative to and in contact with the mating face of another component.	A method in which one component is moved in an angular oscillating motion about a common component axis relative to and in contact with the mating face of another component.	A method in which one component is moved in a small circular motion relative to and in contact with the mating face of another component.
			

4.1.2 Direct drive rotational friction welding

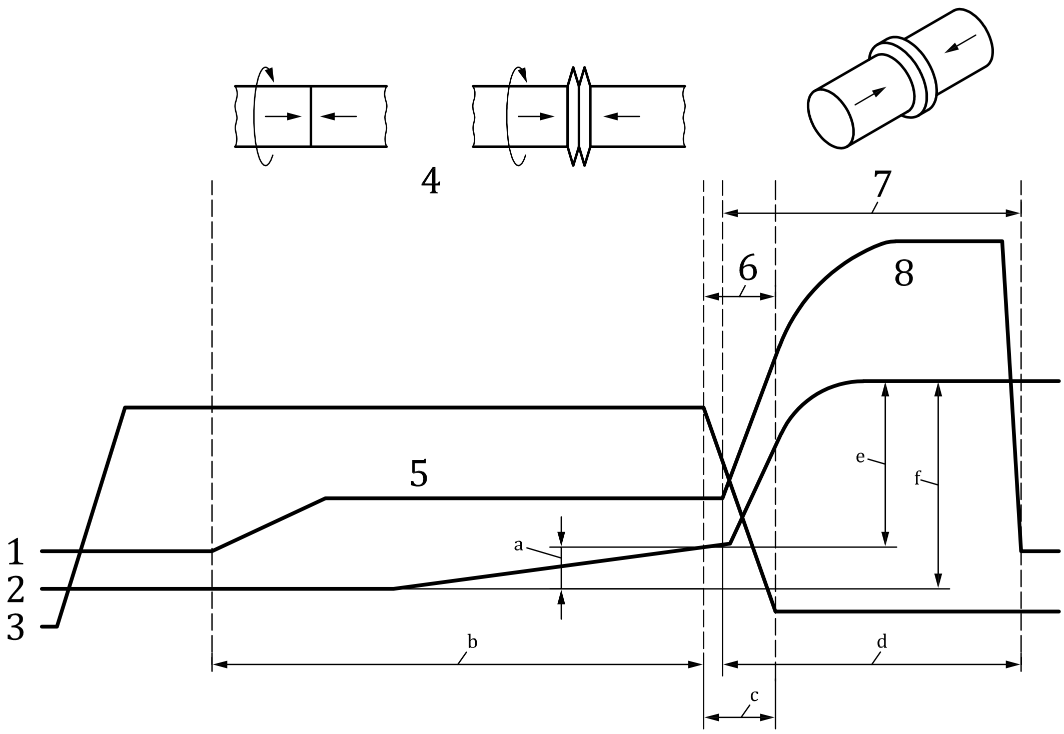
The energy input is provided by direct drive at predetermined rotational speed or speeds (see Figure 1 and Figure 2).



Key

1 drive motor
2 brake
3 rotating clamp
4 stationary clamp
5 rotating workpiece
6 stationary workpiece
7 forge cylinder

Figure 1 — Diagram showing direct drive rotational friction welding



Key

1	axial force	a	Burn-off length.
2	axial displacement	b	Friction time.
3	rotational speed	c	Deceleration time.
4	friction phase	d	Forge time.
5	friction force	e	Forge burn-off length.
6	deceleration phase	f	Total length loss (upset).
7	forge phase		
8	forge force		

Figure 2 — Diagram showing typical relationships of characteristics for friction welding at constant rotational speed (friction welding, process No. 42 in accordance with ISO 4063)

The spindle is either decelerated at a predetermined rate or stopped by external braking or component induced braking. The main welding parameters are listed below and their relationship is given in Annex A:

— rotational speed(s);

— predetermined friction force(s);

— friction time or burn-off;

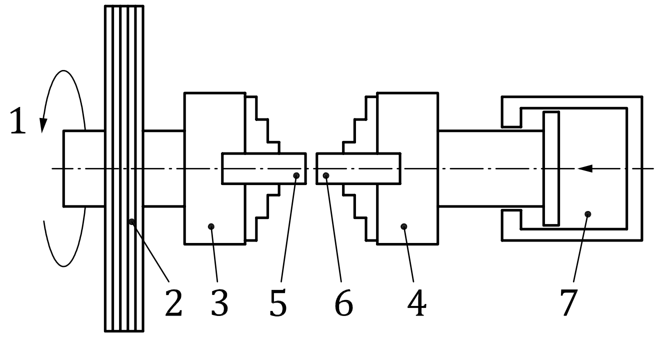
— predetermined forge force(s);

— forge time;

— deceleration time and forge delay.

4.1.3 Stored energy (inertia) friction welding

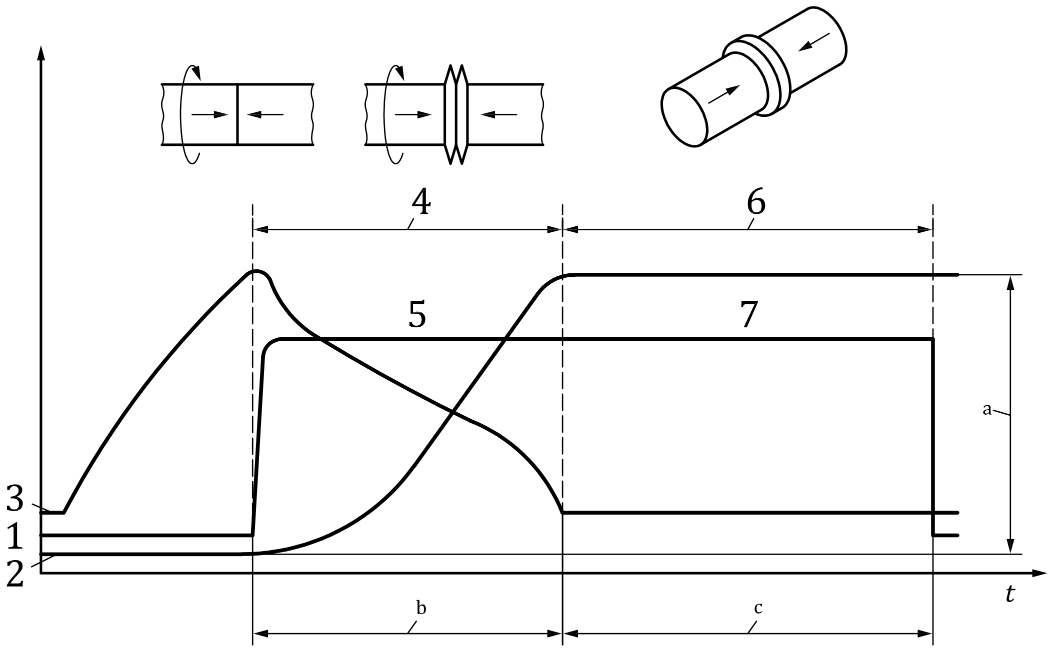
Energy stored in an inertia mass is used up in the friction welding process by component induced braking (see Figure 3 and Figure 4).



Key

1 drive motor
2 inertia mass, variable
3 rotating clamp
4 stationary clamp
5 rotating workpiece
6 stationary workpiece
7 forge cylinder

Figure 3 — Diagram showing inertia friction welding



Key

1 axial force
2 axial displacement
3 rotational speed
4 friction phase
5 friction force
6 forge phase
7 forge force
a Total length loss (upset).
b Friction time.
c Forge time.

Figure 4 — Diagram showing typical relationships of characteristics for inertia friction welding (friction welding, process No. 42 in accordance with ISO 4063)

The main welding parameters are listed below and their relationship is given in Annex A:

— rotational speed;

— inertia mass;

— predetermined friction force(s);

— predetermined forge force(s).

4.1.4 Further processes

Further processes are listed in Annex B.

4.1.5 Friction welding arrangements

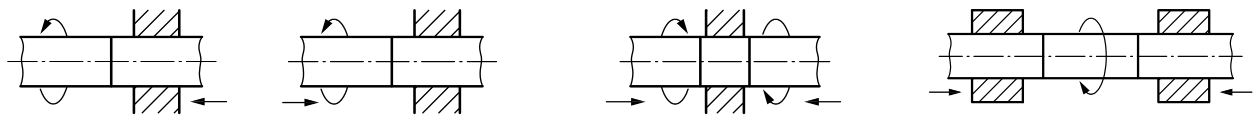
The following methods of rotational friction welding (see Figure 5) can be distinguished:

— friction welding with the rotation of one of the components to be welded and linear movement of the other [Figure 5 a)], i.e. with a fixed head friction welding machine;

— welding with rotation and linear movement of one of the components to be welded and the other one held static [Figure 5 b)] i.e. with a sliding head friction welding machine;

— rotation and linear movement of two components against a static middle component [Figure 5 c)] i.e. with a double ended friction welding machine;

— rotation of central component with linear movement of two end components [Figure 5 d)].



a) b) c) d)

Figure 5 — Rotational friction welding methods

4.2 Materials and material combinations

Experience of friction welding many metallic materials and combinations is already well-documented (see Annex C). Weldability criteria for other welding processes is not always valid for friction welding. More materials and their combinations can be friction welded when compared with most other welding processes. The data shown in Annex C is based upon actual experience from test welds but it is not necessarily complete. For many materials and material combinations, there is further data available which is only valid for particular geometries.

The following factors can affect welding quality:

— amount, distribution and shape of non-metallic inclusions in the parent material(s);

— formation of intermetallic phases in the weld;

— formation of low melting point phases in the weld;

— porosity in parent material(s);

— thermal softening of hardened materials in the weld;

— hardening of the weld metal heat affected zone;

— hydrogen in parent material(s).

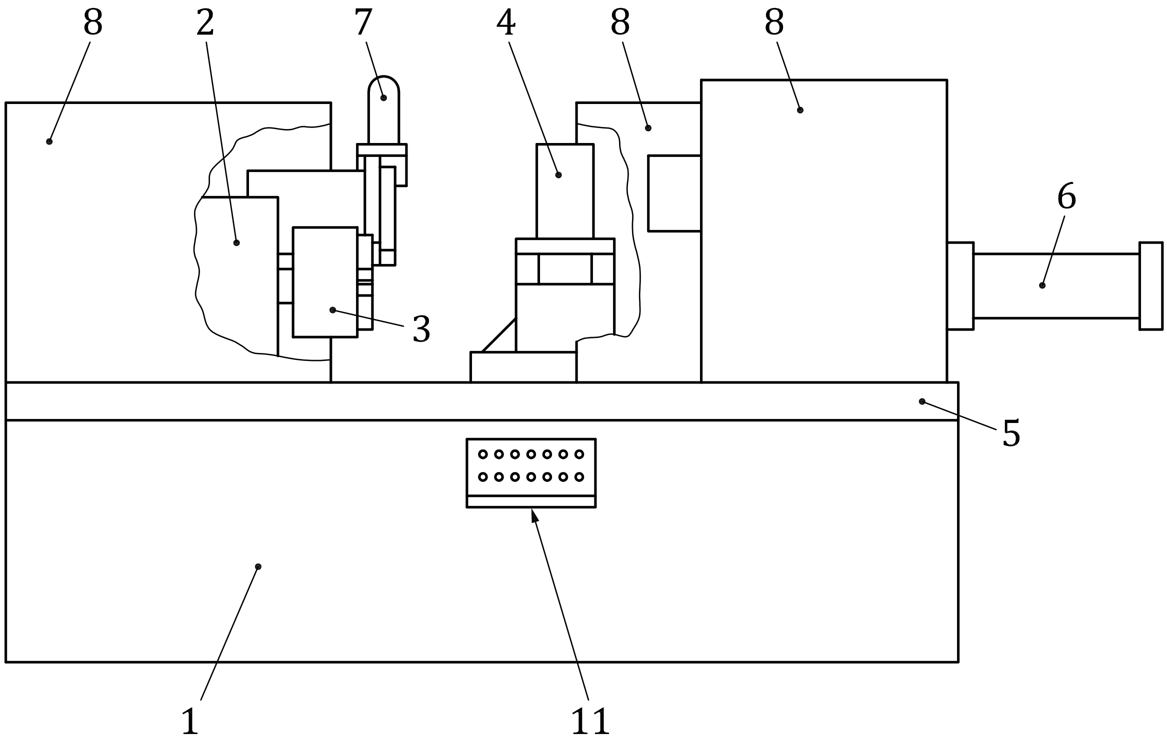
It can be possible to negate some of the above by critical selection of parameters or heat treatment.

4.3 Friction welding machines

4.3.1 General

Friction welding is not sensitive to position and can be performed in any plane.

Machine design and build are dependent upon the welding application and there are preconditions for exact and repeatable production. A schematic diagram of a horizontal friction welding machine is shown in Figure 6.



Key

1 machine frame
2 headstock with drive spindle and brake
3 chuck - for rotating component
4 clamp - for fixed component
5 machine slides (tie-bars)
6 force actuator
7 flash removal unit
8 safety guards
9 hydraulic power pack - not shown
10 electrical control cabinet - not shown
11 machine control panel

Figure 6 — Schematic diagram of a direct drive friction welding machine of horizontal configuration

The application determines the choice of axial force(s), rotation speed(s) and welding time. Other parameters which affect machine design are carriage speed during friction, friction burn-off, braking point, forging point, torque and moment of inertia of the rotating mass.

The repeatability and variation of machine parameters should be checked while the machine is running at operating temperature.

The machine should be of a specification appropriate to the parts to be welded.

The machine should be equipped with an automatic control system which, after the components have been clamped in their work-holding devices and on initiation of the cycle, undertakes a controlled welding cycle without intervention from the operator and incorporates at least the following operational cycle:

— initiation of a sequence which brings the components into face contact at a chosen rotational speed;

— establishment and the maintenance of a friction force(s) and relative speed(s) for the duration of the heating cycle;

— establishment and maintenance of the forge force for a desired forge time or forge distance or combination of both, to complete the weldment.

Unclamping the work-holding devices can be done automatically or not, thus completing the cycle of operations.

4.3.2 Features

Friction welding machines can be equipped with the following options:

— loading equipment;

— unloading equipment;

— turning units for facing, flash removal, machining;

— shearing unit to strip the flash;

— extended memory for welding programmes;

— weld identification unit;

— angular orientation;

— monitoring;

— identification;

— in process proof testing.

5 Quality requirements

5.1 General

The regulations and recommendations which govern other welding processes apply only in part to friction welding.

Emphasis should be placed on the avoidance of imperfections rather than on developing methods to find them. An important prerequisite for ensuring weld quality is the uniformity and consistency of the component to be welded. For this reason, adequate quality assurance measures shall be taken during the pre-welding, welding and post-welding process operations.

5.2 Pre-welding requirements

5.2.1 Condition of raw materials

To ensure repeatable properties of friction welds which remain constant within a friction welding series, the following conditions should be maintained:

— chemical analysis;

— structure;

— strength and hardness;

— dimensional and geometrical tolerances;

— supply conditions of the materials to be joined.

5.2.2 Preparation of the components to be welded

Unless otherwise required by the design specification, the following should be adhered to:

— The end of each component shall be prepared so that the faying surface lies in a plane at right angles to the axis of rotation, the end being cut square. This end can be tapered if required so that the area of the faying surface is reduced for the early stage of the welding cycle. The length of the taper shall be not greater than 50 % of the burn-off length for each component and sufficient to ensure that the plane of the weld interface is on the parallel portion of the component, or at such a position as is indicated on the drawing agreed between the contracting parties.

— Dirt, grease, rust and other surface oxides or protective films shall be removed from the faying surfaces before the components are placed in the machine, except where surface contamination is shown to have no detrimental effect on joint properties.

— Surface irregularities on the faying surface, e.g. centre turning holes, shall only be allowed where they do not cause harmful effects.

5.2.3 Component holding

The torque and axial forces resulting from the friction welding cycle are normally resisted by the tooling. The clamping force shall be not so great as to deform or mark the components beyond acceptable levels.

Suitable backstops are used wherever possible to prevent axial slippage. Plugs may be used to provide additional support when gripping hollow components.

The components to be welded shall be set in the machine so that their axes lie within the limits specified for concentricity and alignment.

To achieve the required alignment, it is sometimes necessary to machine or clean the surfaces of the components to be clamped.

Particular care is necessary with regard to tooling and alignment when welding hollow sections having an outside dimension that is large relative to the wall thickness of the component.

The stick-out shall not be so short as to cause unacceptable chilling of the component or so long as to cause unacceptable misalignment or vibration of the opposing faces during the friction and forge phases.

The two components should be clamped wherever possible so that the stick-out of each is equal, unless the difference in composition or size of the two components makes it desirable for them to have different sticks-out, either to achieve a heat balance or to permit effective work holding.

5.3 Post-welding treatment

Where necessary, further procedures as machining and/or post-weld heat treatment of friction welds shall be carried out in accordance with the expected environmental operating conditions.

5.4 Quality assurance

The system of quality control employed shall take into consideration the following factors:

— production rate and batch size;

— size and design of weldments;

— economic considerations;

— intended operating conditions.

The system employed shall be sufficient to ensure that consistent and satisfactory weld quality is maintained on a batch or individual basis.

The system should ensure that procedures are in place to ensure regular calibration of the friction welding machine.

Production quality control records shall be kept, the form and content of which shall be agreed between the contracting parties.

Guidelines for the level of quality assurance to be used are given in Annex D.

Whether destructive or non-destructive testing methods can be applied depends on the special use of the welded components. A list of destructive and non-destructive testing methods which are generally suitable for friction welding is appended in Annex E. Possible testing procedures are given to facilitate the choice of the most appropriate method.

6 Welding procedure specification (WPS)

6.1 General

The welding procedure specification (WPS) shall give details of how a welding operation is to be performed and shall contain all relevant information about the welding work.

Welding procedure specifications may cover a certain range of cross-sectional areas. Additionally, some manufacturers can prefer to prepare work instructions for each specific job as part of the detailed production planning.

Components used for WPS qualification purposes shall be representative of those used for actual production components in the following respects:

— chemistry;

— faying surface condition;

— heat treatment;

— joint geometry/dimensions.

The information listed below is adequate for most welding operations. For some applications, it can be necessary to supplement or reduce the list. The relevant information shall be specified in the WPS.

Ranges and tolerances, according to the manufacturer's experience, shall be specified where appropriate.

An example of a recommended WPS-format is shown in Annex F.

6.2 Information related to the manufacturer

— Identification of the manufacturer: unique identification;

— Identification of the WPS: alphanumeric designation (reference code) related to a specific friction welding machine.

6.3 Information related to the material

— Material type: identification of the material, preferably by reference to an appropriate standard.

A WPS can cover a group of materials, if agreed prior to production, see 7.1.

— Component information:

  — geometry;

  — dimensions;

  — chemical analysis;

  — other relevant information.

6.4 Welding parameters

All relevant parameters shall be listed (see Clause 4 and Annex F).

6.5 Joint

— Joint design: a sketch of the joint design showing position of weld(s), details and tolerances may be made.

— Preparation of components: selected method of surface preparation, as necessary (e. g. sawing, turning).

— Fixtures:

  — the methods to be used;

  — details of fixtures and backstops.

6.6 Optional devices

For example, flash forming, supports when welding thin-walled tubes.

7 Welding procedure approval

7.1 Principles

The following procedure is designed to meet high duty applications.

Welding procedure specifications for friction welding shall be approved prior to production whenever required. The methods of approval are:

— approval by welding procedure test according to 7.2;

— approval based on previous experience according to 7.4.

This document does not invalidate previous welding procedure approvals made to specifications providing the intent of the technical requirements is satisfied and the previous procedure approvals are relevant to the application and production work on which they are to be employed. Consideration of previous procedure approvals to former national standards or specifications should be, at the time of enquiry or contract stage, agreed between the contracting parties.

7.2 Welding procedure tests

7.2.1 Application

When procedure tests are required, tests shall be carried out:

— in accordance with the application standard

— or according to-the provisions of 7.2.3 to 7.2.6 if no application standard is available.

7.2.2 Preliminary welding procedure specification (pWPS)

The preliminary welding procedure specification shall be prepared in accordance with Clause 6.

7.2.3 Number of test weldments

Unless more severe tests are required by the design specification or by other standards, the minimum test requirements are as follows:

— a minimum of two weldments shall be produced for WPS qualification;

— a minimum of two weldments shall be evaluated.

If one of the test specimens has failed a defined acceptance criteria, then the welding conditions shall be redetermined in order to satisfy the accepted criteria and further two tests specimens shall be evaluated.

Alternative tests can be performed in some cases. The selection of test types and the number of test specimens depend on the performance, safety and quality requirements of the component and assembly and shall be established before any qualification is undertaken. Examples are given in 7.2.5.2.

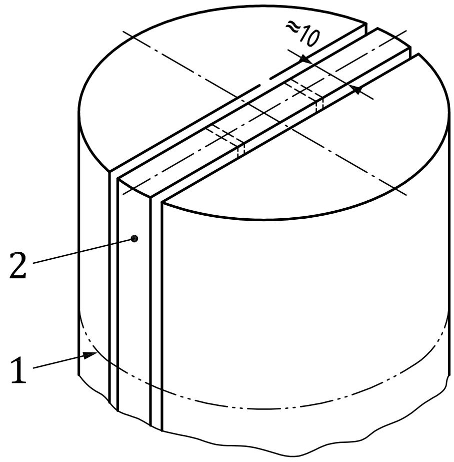
7.2.4 Specification for test specimens

7.2.4.1 Solid sections — Specimens from bar to bar weldments for bend test

The weld shall be dressed flush, unless otherwise agreed by the test specification, having a surface finish that does not affect the result. When components of differing sections are welded together, the larger section shall be reduced to equal that of the smaller after welding.

Specimens shall be tested whole where possible or prepared as shown in Figure 7.

Dimensions in millimetres



Key

1 position of weld interface

2 test specimen for bending

NOTE Guide values:

— thickness: nominal 10 mm;

— width: ≥25 mm;

— length: depending on the component.

Figure 7 — Preparation of specimens for bend testing joints between solid components

If it is necessary to subdivide the test specimens into small specimens, the width of the subdivided specimens shall be not less than 25 mm. Where a specimen results in testing less than one-third of the total area, further 10 mm wide slices shall be cut and tested.

In the preparation of specimens, methods of cutting which significantly affect the metallurgical structure of the specimen shall not be used.

Where bar sections are welded to plate or other components of insufficient thickness to allow a bend test specimen to be prepared, an alternative test procedure shall be agreed between the contracting parties.

7.2.4.2 Hollow sections

7.2.4.2.1 Specimens from tube to tube weldments for bend test

The weld shall be dressed flush on the inside and outside surfaces of the specimen, unless otherwise agreed by the test specification, having a surface finish that does not affect the test result.

Four specimens shall be taken at equal intervals round the weldment (see Figure 8). In the preparation of specimens, methods of cutting which significantly affect the metallurgical structure of the specimen shall not be used. Each specimen shall consist of a parallel sided strip cut so that the weld is approximately central.

The minimum width of each specimen shall be as per Formulae (1) and (2):

— for tubes of outside diameter less than 50 mm:

$$t + D / 10 \tag{1}$$

— for tubes of outside diameter equal to or greater than 50 mm:

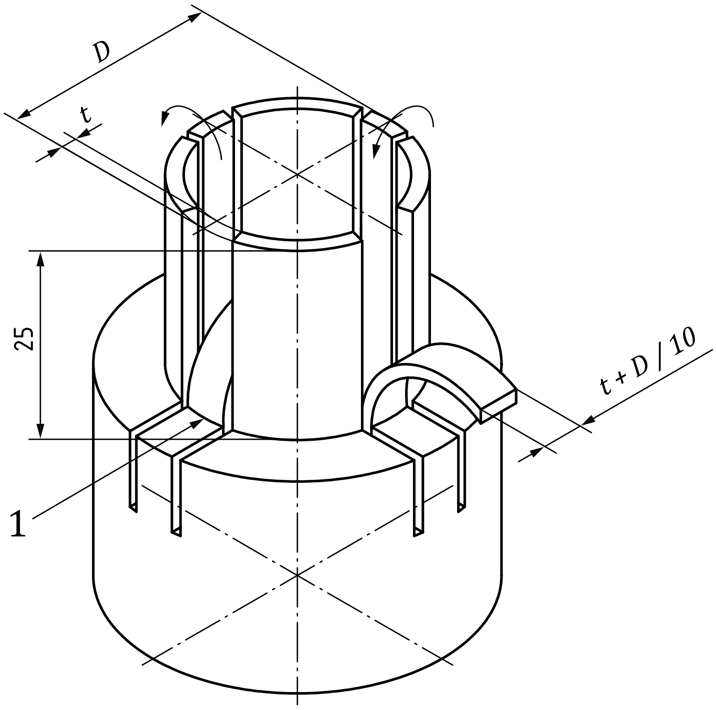
$$t + D / 20 \tag{2}$$

where

t is the wall thickness in millimetres;

D is the outside diameter of the prepared tube in millimetres.

Dimensions in millimetres



Key

1 position of weld

Figure 8 — Specimens for bend testing joints between hollow components and solid or plate components

7.2.4.2.2 Specimens from tube to bar weldments and tube to plate weldments for bend test

The weld shall be dressed flush on the inside and outside surfaces of the specimen having a surface finish that does not affect the test result.

Four test segments shall be cut as shown in Figure 8. The cut shall just penetrate beyond the weld and the heat effected zone.

7.2.5 Test procedures

7.2.5.1 Bend test

Where the dimensions and materials of the test piece are such that a viable bend test cannot be achieved, an alternative procedure shall be stipulated. Otherwise, the requirements given below shall apply.

Specimens prepared shall be bent round a former of diameter suggested in Table 2. The plane of the weld shall be positioned at the apex of the bend. Where specimens have been prepared as in Figure 7, the longer face shall be placed against the former. When bend testing tubular weldments, the number of the test specimens and their relationship to the wall thickness is given in Table 3.

Table 2 — Suggested bend diameters for selected materials

Material	Diameter of former
— carbon steel (0,25 % C max.) — commercially pure aluminium — copper — titanium — austenitic stainless steel	3 *t* to 4 *t*
— carbon steel (over 0,25 % C) — low alloy steel — brasses and bronzes — Al Mn 1	4 *t* to 5 *t*
— all other combinations (similar or dissimilar)	By agreement between the contracting parties
NOTE *t* is the specimen thickness or wall thickness.	

Specimens prepared in accordance with Figure 8 shall be tested by bending two specimens inwards and two outwards. The first inwardly bent specimen shall be shortened, if necessary, to give clearance to itself and the second inward bend. No former shall be used in this test. Bending shall be by light hammer blows at right-angles to the specimen, in a test rig designed for the purpose.

Table 3 — Location of specimens for bend testing of tubular weldments

Thickness	Tension surface
— up to and including 10 mm	— 2 inwards and 2 outwards
— above 10 mm to 20 mm	— 2 inwards and 2 outwards or all 4 side face
— above 20 mm	— all 4 side face

NOTE When making a bend test on a specimen from items from hardenable material, a "knee joint effect" is obtained on both sides of the HAZ with extreme and unpredictable forces in the boundary area. The specimen does not adapt to the diameter of the former. Therefore, post-weld heat treatment to reduce HAZ-hardness can be undertaken prior to performing the bend test, although evaluation procedure can be considered. Also, consideration is given to surface hardened materials where the hardened area can affect mechanical test results.

7.2.5.2 Alternative tests

Alternative tests (see Table 4) may be used in certain instances.

Table 4 — Examples for testing and examination of test specimens

Test specimen	Test type	Extent of testing	
		A (critical welds)	B (non-critical welds)
Bar to bar welds or tube to tube welds	Visual examination	Every weld	Every weld
	Tensile test	2 specimens	—
	Bend test	2 specimens	2 specimens
	Impact testing	1 or 2 sets of specimens	—
	Macrosection	1 weld	—
	Hardness test	1 measurement row	—
Tube to bar or tube to plate welds	Visual examination	Every weld	Every weld
	Tensile test[a]	2 specimens	—
	Bend test[a]	2 specimens	2 specimens
	Impact testing[a]	1 or 2 sets of specimens	—
	Macrosection	1 weld	—
	Hardness test	1 measurement row	—

Depending on the application, two test classes should be distinguished, according to the load:

A: For applications under static stress up to the highest fatigue stress for the parent material.

B: For applications under static stress up to 50 % of the level allowed for the parent material.

[a] If the weld configuration allows this kind of testing.

Further details can be found in Annex E.

7.2.6 Acceptance criteria

Each bend test specimen shall be capable of being bent to the angle agreed on by the test specification, without fracture, although slight tearing shall not be considered a cause for rejection.

NOTE Details of weld imperfections are given in Annex G.

7.3 Welding procedure approval record (WPQR)

All relevant data from the welding of a component needed for approval of a welding procedure specification as well as all results from the testing of the test weld shall be recorded in a welding procedure approval record (WPQR).

An example of a recommended WPQR format is shown in Annex H.

7.4 Previous experience

Approval by previous experience is given when it can be shown by authenticated data that the manufacturer's established production welding procedures have been capable of consistently producing welds of acceptable quality over a period of time.

7.5 Circumstances mandating requalification

A WPS shall remain qualified unless the following occurs:

— modifications or repairs are made to the machine which affect its welding performance;

— materials or material conditions, or both, change from those specified in the WPS;

— preparation of faying surfaces changes from that specified on the WPS;

— unexplained nonconformity with WPS-mandated quality assurance requirements occurs.

7.6 Machine-specific nature of a WPS

A WPS is developed for a specific welding machine; it shall not be used on another machine without requalification, except otherwise agreed.

7.7 Requalification procedure requirements

Requalification procedure requirements are identical to the qualification procedure requirements.

8 Welding personnel

8.1 Friction welding machine operator

Friction welding machine operators shall receive appropriate practical training including safe operating practices.

8.2 Friction welding machine setter

The friction welding machine setter is the person who is competent to set up friction welding equipment according to specified welding procedures.

He has the required knowledge and skill for carrying out the work for quality assurance in the field of friction welding.

The required competence may be proved by sufficient experience, in-house training, or can be by record or certificate of successful participation in a course for friction welders.

8.3 Welding coordination personnel (supervisor)

The manufacturer shall have available suitable welding coordination personnel in order to give the welding personnel the necessary instructions and to perform and supervise the work carefully. The welding coordinator personnel shall have knowledge and experience in the field of friction welding, behaviour of materials and quality assurance. The persons responsible for quality work shall be sufficiently authorised to take all the necessary steps. The duties, interrelations and limits of the spheres of responsibility of those persons should be well defined.

Annex A
(informative)

Relationship of welding parameters

A.1 Welding parameters for direct drive rotational friction welding

A.1.1 General

The friction welding cycle can be conveniently divided into three main phases (friction phase, deceleration phase and forge phase). Each should be operated in such a manner as to ensure that the desired joint properties are achieved. Figure 2 illustrates rotational speed, force and axial shortening with time for friction welding.

A.1.2 Friction phase

The rotational speed(s) and friction force(s) should be applied so that upsetting, once established, occurs continuously throughout the friction phase.

Friction force(s) and rotational speed(s) should be appropriate for joint size and material. Upsetting should be smooth and continuous and be maintained until the end of the burn-off period or length. The burn-off period should be sufficient to generate adequate heat in the weld zone to permit consolidation during forging. All surface irregularities and impurities existing on the faying surfaces are eliminated before the burn-off period is terminated.

A.1.3 Deceleration phase

The function of the deceleration phase is to bring the rotating component to rest in such a way as to promote weld soundness. The time is controlled in conjunction with the application of the forge force.

Duration of the deceleration phase is influenced by one or more of the following:

— power of any braking that is employed;

— control programme when powered deceleration equipment is used;

— energy stored in the moving parts, within the transmission, tooling and workpiece;

— interface area;

— metals being joined;

— forging force.

A.1.4 Forge phase

The forge force required depends on the configuration of the parts and the strength of the metals at the welding temperature. The chosen forge force should ensure a sound weld. It is possible that a low forge force not be sufficient to expel debris and an excessive forge force can lead to unacceptable distortion of the microstructure. Also, the force should not be such as to cause unacceptable distortion of the work or excessive expulsion of the plastic material, either of which can lead to a reduction in joint strength. The forge force should be maintained for a sufficient time to consolidate the interface.

A.2 Welding parameters for stored energy (inertia) friction welding

A.2.1 General

Stored energy friction welding consists of simultaneous application of axial thrust and stored rotational energy to the faying surfaces of the two components to be welded. Figure 4 is a typical diagram of rotational speed, force and axial movement of this variant. The two main parameters, energy and axial force, may be considered.

A.2.2 Energy

The energy to make a weld is obtained from, for example, the rotating mass of spindle, transmission, flywheels or tooling.

In rotating energy systems, the amount of energy calculated to be necessary for the weld is obtained from the rotating mass turning at a rotational speed within the correct speed range for the metals to be welded. Therefore, it is necessary to use the required mass and speed to provide the necessary energy.

A.2.3 Axial force

The required axial force is determined by the geometry and material of the components to be welded.

The force is applied when the spindle has reached the chosen speed and the drive has been disconnected. The same force may be maintained throughout the friction, arrest and forge phases of the cycle although a higher forge force may be beneficially applied for some metals.

Annex B
(informative)

Additional processes based on friction

B.1 Radial friction welding

A method whereby hollow components can be joined by using an intermediate ring which is rotated between them while subjected to radial forces. These forces can be generated by either compressing or expanding the ring.

B.2 Friction stud welding

A method whereby a solid or hollow component (stud) is friction welded to a larger component.

B.3 Friction surfacing

A method of deposition whereby friction between the surfacing material and the substrate is used to provide the thermo-mechanical conditions for adhesion.

B.4 Friction taper plug welding

A method whereby a solid or hollow tapered component is friction welded into a tapered hole in the other component.

B.5 Friction taper stitch welding

A method according to friction taper plug welding using solid components where a series of single plug welds are overlapped.

B.6 Friction stir welding

A method whereby a non-consumable tool is rotated between the butting or overlapped surfaces of two components and translated to generate heat and material flow and a consequent friction weld.

B.7 Friction seam welding

A friction welding method whereby a consumable material is rotated and translated between the butting surfaces of two components, e. g. two sheets or plates.

B.8 Friction lap seam welding (the Luc process)

A technique where a high-speed non-consumable rotary wheel is offered against two components, which are overlapped, then translated to effect a friction weld between the components.

B.9 Friction plunge welding

A technique whereby a hard material component with a specially machined re-entrant feature is friction welded into a component of softer material to produce both a mechanical lock and a metallurgical bond.

B.10 Third body friction welding

A method whereby two components are friction welded together using a third body material, and specially machined features. The third body material can take the form of a solid, powder and/or metal chippings (swarf).

B.11 Friction co-extrusion cladding

A method whereby an inner component can be clad with an outer component as they are rotated and forced co-axially through a specially shaped die. For long parts, the die can be rotated.

B.12 Friction hydro-pillar processing

A method whereby a solid rod or tubular is rotated, under an axial force, into a cavity in order to completely fill the cavity. The method can be used for repair, fabrication, cladding and reprocessing of materials.

B.13 Friction brazing

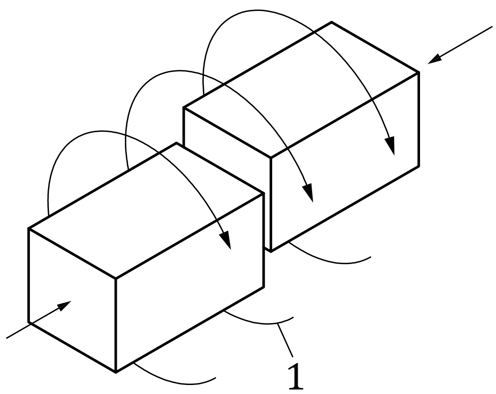
A method of joining with a pre-placed braze alloy, where the energy to produce the bond is developed by friction through relative motion of one component under light force against the braze layer on the other component.

B.14 Linear friction welding

A method in which one component is moved in a linear oscillating motion relative to and in contact with the mating face of another component.

B.15 Orbital friction welding

A method in which each point in the contact surface orbits a different point. The orbit has a constant rotational speed and is identical for all points in the joint interface. At the end of a weld, the relative movement is ended by returning both parts to the common axis of the machine and the welding force is maintained or increased (See Figure B.1)



Key

1 orbit

Figure B.1 — Orbital friction welding

B.16 Overlap friction welding

A process in which two components with axial force acting on the initially overlapping surface(s) are friction-welded one above the other with beginning plasticization, forming conical connecting interfaces.

B.17 Friction mash seam welding

A process in which a rotating friction disc over the butt or overlapped surfaces of two parts is used to generate heat and material flow and thereby a pressure welded joint between the parts by frictional heating is formed.

B.18 Friction element welding

A process in which overlapping sheets or components are joined by rotational friction welding of a specially formed friction element to the base sheet, thereby producing a rivet-like clamping of the overlapping sheets or components.

Annex C
(informative)

Material combinations weldable by friction welding

	Tungsten copper PM	Tungsten PM	Titanium and titanium alloys	Free cutting steel	Steel PM	Steel casting	Steel, high-alloyed (austenitic)	Steel, high-alloyed (ferritic)	Steel, low-alloyed	Steel, unalloyed	Niobium	Nickel alloys PM	Nickel and nickel alloys	Molybdenum PM	Magnesium and magnesium alloys	Copper and copper alloys	Hard metal, tool steel	Cast iron	Aluminium PM	Aluminium and aluminium alloys
Aluminium and aluminium alloys	•	•	•	•	•	•	•	•	•	•			•		•	•	•	•	•	•
Aluminium PM							•	•	•	•									•	
Cast iron					•	•	•	•	•	•								•		
Hard metal, tool steels							•	•	•	•							•			
Copper and copper alloys	•	•	•	•	•	•	•	•	•	•						•				
Magnesium and magnesium alloys										•					•					
Molybdenum PM														•						
Nickel and nickel alloys			•				•	•	•	•		•	•							
Nickel alloys PM			•						•	•		•								
Niobium			•				•	•			•									
Steel, unalloyed		•	•	•	•	•	•	•	•	•										
Steel, low-alloyed		•	•	•	•	•	•	•	•											
Steel, high-alloyed (ferritic)				•	•	•	•	•												
Steel, high-alloyed (austenitic)		•	•	•	•	•	•													
Steel casting				•	•	•														
Steel PM				•	•															
Free cutting steel				•																
Titanium and titanium alloys			•																	
Tungsten PM	•	•																		
Tungsten copper PM	•																			

• Weldable

[] Little or no experience

PM Powder metallurgy

NOTE This schematic diagram gives no information regarding weld quality which is application-dependent.

Annex D
(informative)

Guidelines for quality assurance

The level of quality assurance is determined by conditions of use and applied stresses on the friction weldments. Three categories (A, B or C) can be used:

— Category A: Where failure of welded components is dangerous for the product and the environment.

— Category B: Where failure of welded components will cause considerable damage.

— Category C: Where failure of welded components will cause limited damage.

Table D.1 — Alternative application and tests

Category	Visual examination	Check of total length loss	Parameter monitoring[a]	Recording of parameters	Destructive testing mechanical and micrographic	Non-destructive testing
A	100 %	100 %	—	100 %	[b]	[c]
	—	—	100 %			
B	100 %	10 %	—	To be defined	[b]	[c]
	—	—	50 %			
C	50 %	5 %	—	Periodic, at least once every 6 months	[b]	[c]
	—	—	20 %			

[a] At least monitoring of friction pressure, forge pressure, burn-off length, total length loss and time.

[b] Frequency to be defined, whichever the category.

[c] The application of non-destructive testing depends on conditions of use and further machining. Weldments which are subjected to dynamic loads in service without removal of the upset material should be tested non-destructively after removal of the upset material when developing the WPS.

NOTE 1 Visual examination: All applicable alternatives within categories A, B and C contain the visual examination in a certain scale. Visual examination is not possible in automated friction welding machines. Therefore, an alternative is given in Table D.1. The requirements are accordingly higher.

NOTE 2 Recording of parameters provides the opportunity of a possible modification of parameters and to ensure traceability.

Annex E
(informative)

Examination and test

E.1 Non-destructive testing

E.1.1 General

Prior to testing permissible and non-permissible characteristics and results are to be specified in the test specification.

Of course, each testing method has its restrictions which are dependent on the welding process, material and component geometry. Therefore, it is sometimes necessary to determine a suitable test procedure to be used for a particular welded assembly. The flash may be removed before testing or not.

E.1.2 Visual examination

Visual examination provides an initial impression of shape and appearance. Attention should be paid in particular to:

— the shape and size of the flash;

— the axial and angular deviation.

Variation of the flash profile indicates that changes have occurred in material, workpiece geometry, welding conditions or work holding.

ISO 17637 can be used.

E.1.3 Dimension check

With this test axial misalignment, angular deviation and length variations in welded assemblies are measured.

Discrepancies in the material or process (preparation, welding) result either in insufficient or excessive total length loss, which is, of course, a statement about the quality in itself.

E.1.4 Dye penetration test

Fine cracks and fissures on the surface can be revealed by using dye penetration test after flash removal.

ISO 23277 can be used.

E.1.5 Magnetic particle test

This test is suitable for determining whether there are notches or fissures in the surface area of ferromagnetic components. The flash has to been removed before this test can be applied.

ISO 17638 can be used.

E.1.6 Eddy current test

Following flash removal this testing procedure can be employed to detect any fissures, notches or non-homogeneity in the surface area to a depth of approximately 0,3 mm.

ISO 3452-1 can be used.

E.1.7 Ultrasonic test

Ultrasonic testing can be used to find cracks or lack of bond imperfections. However, it cannot detect imperfections which weaken the weld such as fine oxide films, stuck (kissing) bonds.

ISO 10863, ISO 13588 or ISO 17640 can be used.

E.2 Destructive testing

E.2.1 General

Destructive testing shall be applied to production weldments or, where appropriate, to welded test pieces representative of the actual weldment.

Each specimen should be representative. Attention should be paid to any possible changes in the material characteristics. Methods of cutting which seriously affect the metallurgical structure of the specimen shall not be used.

E.2.2 Tensile test

If components are very large, the welded assembly should be divided into sections. The specimens should be cut in an axial direction and include the periphery and central area of the weldment.

E.2.3 Impact test

Generally with friction welding the zone which is affected by the process itself is very narrow. Here, as is the case with all other pressure welding methods, the significance of the impact values is not the same as that of fusion welding processes (fibre deflection). Whether or not an increase in the impact value is necessary depends on intended service conditions.

E.2.4 Metallographic examination

This examination is employed to examine the metallurgical characteristics of the friction weld. These features can include micro structure, heat-affected zone, interface, lack of bond, inclusions and defects. An important factor is the hardness survey.

Sections for micro and macro examinations should be taken from the centre and the peripheral regions of the weld.

E.3 Proof testing

Where practical considerations allow and when specified in the test specification, an approved method of proof testing can be applied to an agreed percentage of production weldments. Where such methods are employed, the applied loads should be greater than those expected in service and the component tested shall subsequently show no damage likely to cause failure in service.

Annex F
(informative)

Manufacturer's friction welding procedure specification (WPS)

No.: ________________

Company: ____

____

Component: ____

Job No.: ____

Drawing No.: ____

WPQR No.: ____

Welding coordinator: ____________________________

____

____

Customer: ____

Customers Contract No.: ________________________

Examiner or Examining body: ________________

Welding machine reference: ________________

Tooling: ________________________________

____

____

Back stop: ________________________________

____

____

Flash removal: ☐ Yes ☐ No

Tooling: ________________________________

____

Parameters of flash removal: ________________

____

____

Sketch

Materials

Materials	Rotating component	Non-rotating component
Material		
Material condition		
Preparation of faying surfaces		
Welding cross-section in mm^2		

Tolerances required (post weld)

Joint	Length tolerance mm	Mismatch mm	Angular deviation °

Remarks: ____

____

____

Welding coordinator

Examiner or Examining body

____________________ ____________________

Name, date and signature

Name, date and signature

Additional data

Code[a]	Denomination	Units	Values	Remarks
A	**Component information**			
		mm		
		mm		
B	**Machine settings**			
	Friction rotation speed(s)	min^{-1}		
	Gauge pressure setting(s) (contact)	MPa (bar)		
	Gauge pressure setting(s) (friction)	MPa (bar)		
	Friction force	kN		
	Gauge pressure setting(s) (forge)	MPa (bar)		
	Forge force	kN		
	Contact time	s		
	Friction time	s		
	Burn-off	mm		
	Gauge pressure setting (brake)	MPa (bar)		
	Burn-off rate	mm/s		
	Brake point/brake delay	s		
	Forge point/forge delay	s		
	Forge time	s		
C	**Post weld data**			
	Total loss of length	mm		
	Total weld time	s		
D	**Remarks**			
	Heat treatment			

[a] Additional data if required.

Annex G
(informative)

Characteristics of friction welded components

Table G.1 shows imperfections that can occur in friction welded joints. The table indicates also why they occur and remedial measures for corrections are suggested. It assists standardized terminology.

Table G.1 — Characteristics of friction welded components

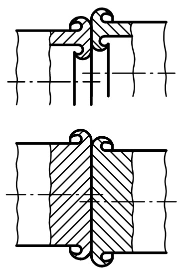
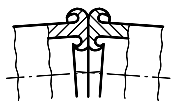
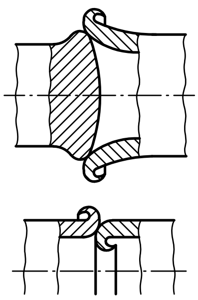
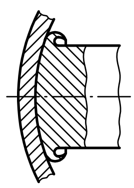
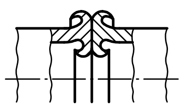
Designation	Explanation	Diagram	Usual test methods	Cause	Remedy	Remarks
1 Shape deviation						
Axial misalignment	Misalignment of parallel axes of components		Measurement, visual examination, macroscopic	Clamps, geometrical inaccuracy, stick-out too long, poor component preparation, angularity	Adjustment of clamps, check component geometry, reduce free length, better component preparation	Critical mainly when friction welding thin-walled tubes and materials which are very dissimilar
Angular deviation	Axes of components misaligned		Measurement, visual examination	Clamping length too short, stick-out too long, loose clamps, axial force too great	Improve clamping decrease free length, tighten clamps, reduce axial force	Critical mainly when welding thin-walled tubes
Parts overlying	Lateral deviation of one or both workpieces		Visual examination, macroscopic	Welding parameters, component geometry, stick-out too long, axial misalignment, workpiece preparation, angularity	Change	Critical mainly when friction welding thin-walled tubes and components of very dissimilar materials
Deformation of work-pieces	Undesired change in geometry	Examples:  Bending  Flattening	Measurement, visual examination	Insufficient support, axial strength too high, stick-out too long, tooling wear	Adjust clamping, increase rigidity	Occurs when welding thin-walled work-pieces

Table G.1 *(continued)*

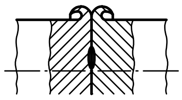
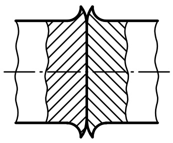
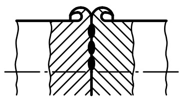
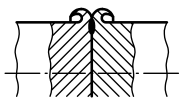
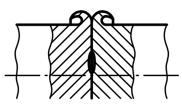
Designation	Explanation	Diagram	Usual test methods	Cause	Remedy	Remarks
2 Unsatisfactory joint						
Interface defect	Incomplete bonding		Macro- and micrographs, examination of fractured ends, non-destructive testing	Clamps, welding parameters, workpiece preparation, centrally drilled hole, impurities	Change parameters, better workpiece reparation	
Undercut	Undercut below component diameter		Visual examination, magnetic particle test, dye penetration test, ultrasonic test	Welding parameters, component preparation, workholding alignment	Change parameters, better component preparation	Energy input too low, burn off (weld time) too short
Inclusions	Non-metallic inclusions in the welding area		Macro-/micro-graphs, examination of fracture	Component preparation, welding para-meters, pollution of welding surfaces due to casting skin, rust, scale, lubricants, grease etc., dirty central hole, high level of inclusions in component metal	Clean welding surfaces, if necessary drill central hole, use clean material	
Cracks	Partial non-coalescence of components on the periphery of the weld interface		Dye penetration test, magnetic particle test, macro- and micrographs	Hardening, inner tension due to incorrect heating	Heat treatment before/after welding, change parameters, use different materials	Low critical cooling rate, e.g. when using high-carbon steel or high-speed steel, remove flash before heat treatment
	Non-coalescence in the middle		Sections, ultrasonic test	Hardening, incorrect heating, short weld time	Heat treatment before/after welding, change parameters, use different materials, increase axial force, bevel end	

Table G.1 *(continued)*

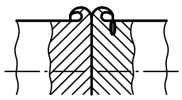
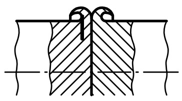
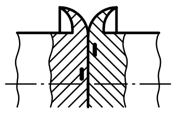
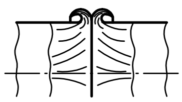
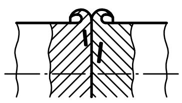
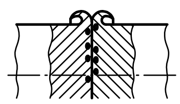
Designation	Explanation	Diagram	Usual test methods	Cause	Remedy	Remarks
	On the periphery or in the HAZ		Sections, visual examination, eddy current test, ultrasonic test, dye penetration test, magnetic particle test	Hardening, incorrect heating, presence of carbides, MnS- inclusion		
Cracks	In the sharply delineated transition to flash		Macro- and micrographs, visual examination, eddy current test, dye penetration test, magnetic particle test	Forging pressure too high, stick-out too short	Lower forge pressure, modify parameters, increase rotational speed	
	Appears in HAZ near weld line, due to hydrogen		Non-destructive testing	Presence of hydrogen in one or both components, e.g. Castings + plated metals	Apply hydrogen release heat treatment	Can occur up to 1 000 hours after welding
3 Microstructural features						
Peaks and troughs in hardness	Hardness and/or consistency values differ from those of base material		Determination of distribution of hardness values	Welding parameters, material, material preparation	Change parameters, heat treatment	
Gross distortion in grain structure	Grain structure of base material distorted due to friction welding		Metallography	Weld parameter incorrect	Material without segregational bands, modify parameters, increase r.p.m., decrease axial strength	Possible cause for low ductility in the joint area, especially if non-metallic inclusions present
Inter-metallic phases	Diffusion of elements		Macro-/micro-graphs	Welding parameters in particular for dissimilar materials components	Change material and/or parameters, e.g. Decrease welding time	If present, severely embrittle weld
Carbide, oxide, nitride agglomerations in the welding zone	Appear on welding surfaces after welding		Macro-/micro-graphs, ultrasonic test to a certain degree		Better homogeneity of material, change weld parameters, e.g. Shorten welding time	

Table G.1 *(continued)*

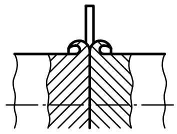
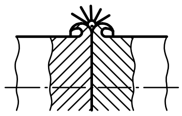
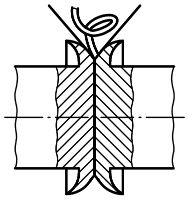
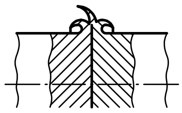
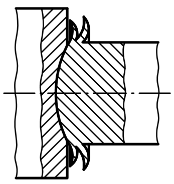
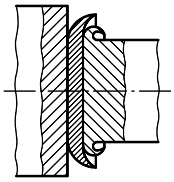
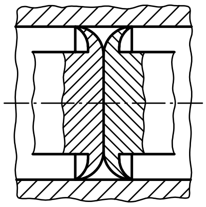
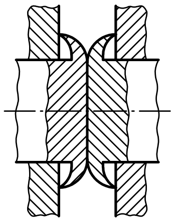
Designation	Explanation	Diagram	Usual test methods	Cause	Remedy	Remarks
4 Flash deviations						
Burr	Vertically in the flash		Visual examination, magnetic particle test, dye penetration test	Forging pressure too high, insufficient heat, vertical fissures in base material	Change parameters, increase rotation speed	Occurs e.g. In free machining steel alloys, tooling steels containing W, no problem if they do not penetrate into component
Burr	Extrusion of material all the way around		Visual examination	Unknown	Unknown	Consequences unknown
	Material protrudes in a spiral shape at irregular intervals		Visual examination	Insufficient heat input	Increase energy input by increasing r.p.m.	
	At regular intervals		Visual examination	Unknown	Unknown	
Secondary flash I	Assymetrical welding flash		Visual examination	Very dissimilar materials or workpieces		For steel stud type welds or components of differing section; it is good to develop flash from plate or bigger section

Table G.1 *(continued)*

Designation	Explanation	Diagram	Usual test methods	Cause	Remedy	Remarks
Secondary flash II	Displacement of welding surfaces			Welding parameters	Change welding parameters, increase friction force	It is bad if secondary flash sits on plate (bigger section) and has come from stud (smaller section)
Flash restriction	Deforms against tooling	 	Visual examination	Inadequate stick-out and poor tooling	Increase stick-out and improve tooling	Reduces welding pressures, can increase cooling rate. However ,can be used to advantage.

Annex H
(informative)

Welding procedure approval record form (WPQR) Welding procedure approval — Test certificate

No.: ____________________

Company: ____________________

Examiner or Examining body: ____________________

Component: ____________________

Welding machine reference: ____________________

Job No.: ____________________

Drawing No.: ____________________

Tooling: ____________________

WPQR No.: ____________________

Welding coordinator: ____________________

Back stop: ____________________

Customer: ____________________

Customers contract No.: ____________________

Flash removal: ☐ Yes ☐ No

Tooling: ____________________

Parameters of flash removal: ____________________

Sketch

Materials

Materials	Rotating component	Non-rotating component
Material		
Material condition		
Preparation of faying surfaces		
Welding cross-section in mm^2		

Tolerances required (post weld)

Joint	Length tolerance mm	Mismatch mm	Angular deviation °

Remarks: ____

____

____

____

Welding coordinator

____

Name, date and signature

Examiner or Examining body

____

Name, date and signature

Additional data

Code[a]	Denomination	Units	Values	Remarks
A	**Component information**			
		mm		
		mm		
B	**Machine settings**			
	Friction rotation speed(s)	min^{-1}		
	Gauge pressure setting(s) (contact)	MPa (bar)		
	Gauge pressure setting(s) (friction)	MPa (bar)		
	Friction force	kN		
	Gauge pressure setting(s) (forge)	MPa (bar)		
	Forge force	kN		
	Contact time	s		
	Friction time	s		
	Burn-off	mm		
	Gauge pressure setting (brake)	MPa (bar)		
	Burn-off rate	mm/s		
	Brake point/brake delay	s		
	Forge point/forge delay	s		
	Forge time	s		
C	**Post weld data**			
	Total loss of length	mm		
	Total weld time	s		
D	**Remarks**			
	Heat treatment			

[a] Additional data if required.

Test results

Specimen no.	Bending angle °	Location of fracture	Remarks	Assessment

Further remarks:

Bibliography

[1] ISO 3452-1, *Non-destructive testing — Penetrant testing — Part 1: General principles*

[2] ISO 4063, *Welding and allied processes — Nomenclature of processes and reference numbers*

[3] ISO 10863, *Non-destructive testing of welds — Ultrasonic testing — Use of time-of-flight diffraction technique (TOFD)*

[4] ISO 13588, *Non-destructive testing of welds — Ultrasonic testing — Use of automated phased array technology*

[5] ISO 17637, *Non-destructive testing of welds — Visual testing of fusion-welded joints*

[6] ISO 17638, *Non-destructive testing of welds — Magnetic particle testing*

[7] ISO 17640, *Non-destructive testing of welds — Ultrasonic testing — Techniques, testing levels, and assessment*

[8] ISO 17643, *Non-destructive testing of welds — Eddy current testing of welds by complex-plane analysis*

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