INTERNATIONAL STANDARD

ISO 15620

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2000-07-15

Welding — Friction welding of metallic materials

Soudage — Soudage par friction des matériaux métalliques

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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 3.

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 member bodies casting a vote.

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

International Standard ISO 15620 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee TC 44, *Welding and allied processes*, Subcommittee SC 10, *Unification of requirements in the field of metal working*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this standard, read "...this European Standard..." to mean "...this International Standard...".

Annexes A to H of this International Standard are for information only.

For the purposes of this International Standard, the CEN annex regarding fulfilment of European Council Directives has been removed.

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Foreword

The text of EN ISO 15620:2000 has been prepared by Technical Committee CEN/TC 121 "Welding", the secretariat of which is held by DS, in collaboration with Technical Committee ISO/TC 44 "Welding and allied processes".

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2001, and conflicting national standards shall be withdrawn at the latest by January 2001.

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this standard.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

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.

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

1 Scope

This standard 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 standard is appropriate where a contract, an application standard or 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 may be adopted in full or some may be deleted, if not relevant to the construction concerned.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 1289
Non-destructive examination of welds – Penetrant testing of welds – Acceptance levels

EN 1290
Non-destructive examination of welds – Magnetic particle examination of welds

EN 1711
Non-destructive examination of welds – Eddy current examination of welds by complex plane analysis

EN ISO 4063
Welding and allied processes – Nomenclature of processes and reference numbers (ISO 4063:1998)

3 Terms and definitions

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

3.1
axial force
Axial force between components to be welded.

3.2
axial pressure
Pressure (force per unit area) on the faying surfaces.

3.3
burn-off length
Loss of length in the friction phase.

3.4
burn-off rate
The rate of shortening of the components during application of the friction force.

3.5
component
A single item before welding.

3.6
component induced braking
Reduction in rotational speed resulting from friction between the interfaces.

3.7
contact force
Axial force on contact of components.

3.8
contact torque
Reaction torque after friction start.

3.9
external braking
External braking reducing the rotational speed.

3.10
faying surface
A surface of one component that is to be in contact with a surface of another component to form a joint.

3.11
forge force
The force applied normal to the faying surfaces at the time when relative movement between the components is ceasing or has ceased.

3.12
forge length
The amount by which the overall length of the components is reduced during the application of the forge force.

3.13
forge phase
In the friction welding cycle the interval between the start and finish of application of the forge force.

3.14
forge pressure
The pressure (force per unit area) on the faying surfaces resulting from the axial forge force.

3.15
forge rate
The rate of shortening of the components during the application of forge force.

3.16
forge time
The time for which the forge force is applied to the components.

3.17
friction force(s)
The force(s) applied normal to the faying surfaces during the time that there is relative movement between the components.

3.18
friction phase
In the friction welding cycle the interval in which the heat necessary for making a weld is generated by relative motion and the friction force(s) between the components, i.e. from contact of components to the start of deceleration.

3.19
friction pressure(s)
The pressure(s) (force per unit area) on the faying surfaces resulting from the axial friction force.

3.20
friction time
The time during which relative movement between the components takes place at rotational speed and under application of the friction force(s).

3.21
interface
The contact area developed between the faying surfaces after completion of the welding operation.

3.22
length allowance
Extra material to allow for loss of length.

3.23
overhang
The distance a component projects from the fixture, or chuck in the direction of the mating component.

3.24
peripherial velocity
Velocity of outer diameter of faying surfaces to be welded.

3.25
rotational speed
Revolutions per minute of rotating component.

3.26
stopping phase
In the friction welding cycle the interval in which the relative motion of the components is decelerated to zero.

3.27
stopping time
The time required by the moving component to decelerate from friction speed to zero speed.

3.28
torque curve
Torque characteristic between the two interfaces based on time (contact, equilibrium, final torque).

3.29
total length loss (upset)
The loss of length that occurs as a result of friction welding, i.e. the sum of the burn-off length and the forge length.

3.30
total weld time
Time elapsed between component contact and end of forging phase.

3.31
upset metal (flash)
Parent metal proud of the normal surfaces of the weldment as a result of friction welding.

3.32
weld cross-section
The areas to be welded.

3.33
welding cycle
The succession of operations effected by the machine for making a weldment and the return to the initial position (excluding component-handling operations).

3.34
weldment
Two or more components joined by welding.

3.35
pressure contact area
The surface contact area of the components through which the force is transmitted.

4 Welding knowledge

4.1 Process

The classification of friction welding processes are listed in table 1.

Table 1 - Classification of friction welding processes

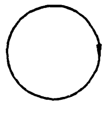
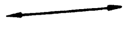
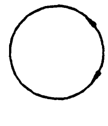
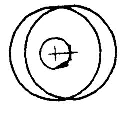
Friction welding

- **Relative motion classification**
- **Energy classification**

Continuous drive	**Stored energy**
The process variant where power or energy is provided by an infinite duration source and maintained for a preset period	The process variant where the energy for welding is supplied by the kinetic energy stored in a rotating system or fluid storage system

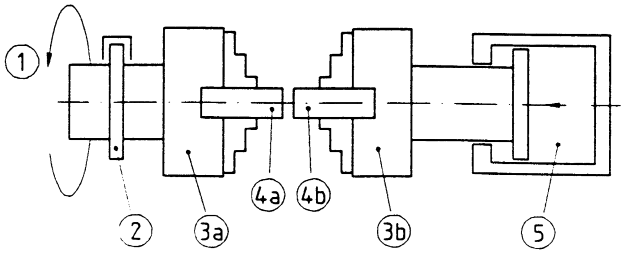
Hybrid system

Combining some features of both methods

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.
			

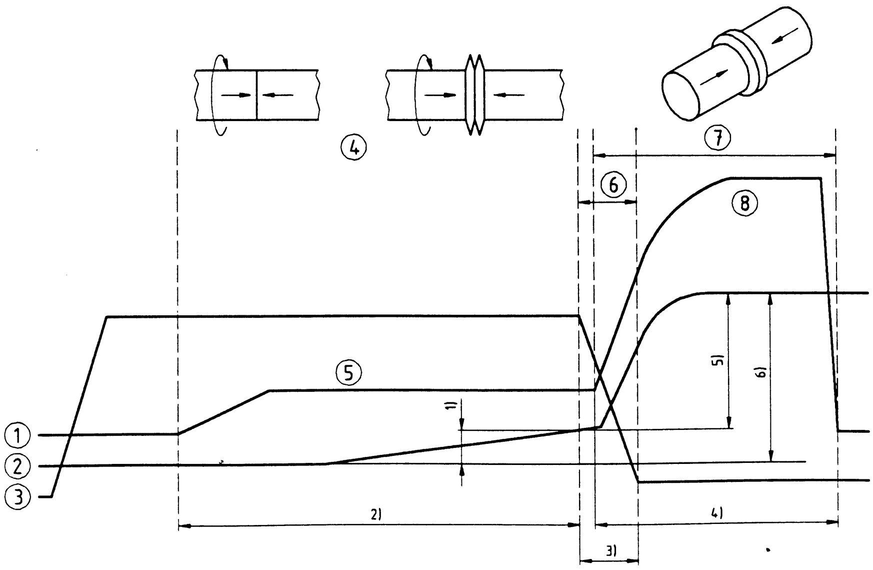
4.1.1 Direct drive rotational friction welding

The energy input is provided by direct drive at predetermined rotational speed or speeds, figures 1 and 2.



1 Drive motor
2 Brake
3a Rotating clamp
3b Stationary clamp
4a Rotating workpiece
4b Stationary workpiece
5 Forge cylinder

Figure 1 - Diagram showing direct drive rotational friction welding



1 Axial force
2 Axial displacement
3 Rotational speed
4 Friction phase
5 Friction force
6 Stopping phase
7 Forge phase
8 Forge force

1) Burn-off length
2) Friction time
3) Stopping time
4) Forge time
5) Forge length
6) Total length loss (upset)

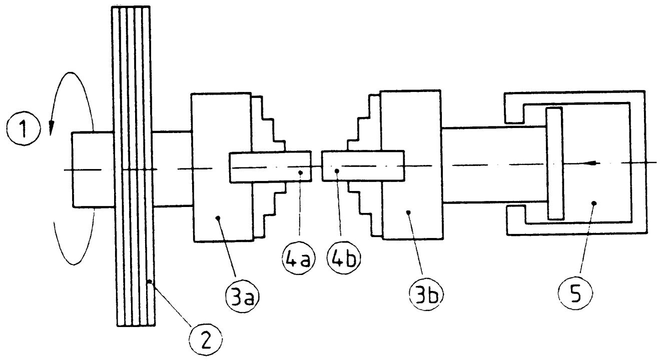
Figure 2 - Diagram showing typical relationships of characteristics for friction welding at constant rotational speed (friction welding, process No. 42 in accordance with EN ISO 4063)

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;
– stopping time and forge delay.

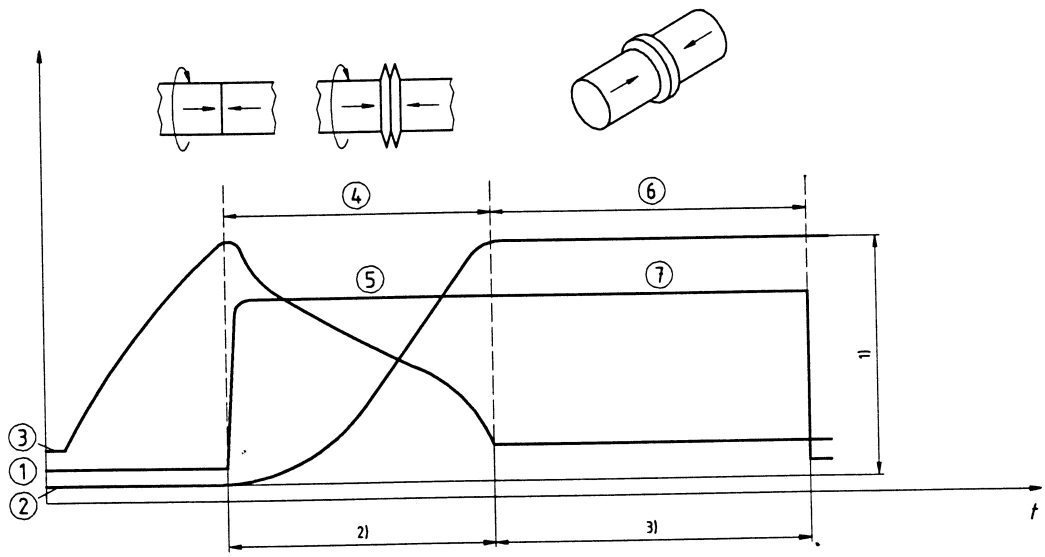
4.1.2 Stored energy (inertia) friction welding

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



1 Drive motor
2 Inertia mass, variable
3a Rotating clamp
3b Stationary clamp
4a Rotating workpiece
4b Stationary workpiece
5 Forge cylinder

Figure 3 - Diagram showing inertia friction welding



1 Axial force
2 Axial displacement
3 Rotational speed
4 Friction phase
5 Friction force
6 Forge phase
7 Forge force

1) Total length loss (upset)
2) Friction time
3) Forge time

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

4.1.3 Further processes

Further processes are listed in Annex B.

4.1.4 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 or one of the parts to be joined and linear movement of the other (figure 5a) i.e. 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 5b) i.e. sliding head friction welding machine;

– rotation and linear movement of two components against a static middle component (figure 5c) i.e. double ended friction welding machine;

– rotation of central component with linear movement of two end components (figure 5d).

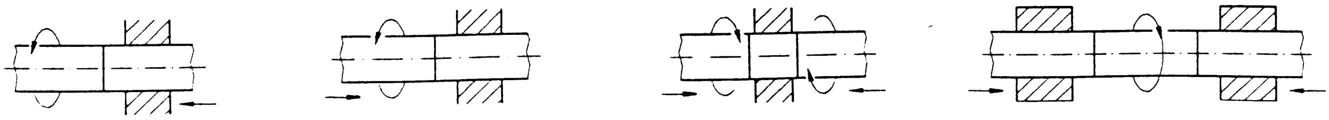


Figure 5a   Figure 5b   Figure 5c   Figure 5d

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).

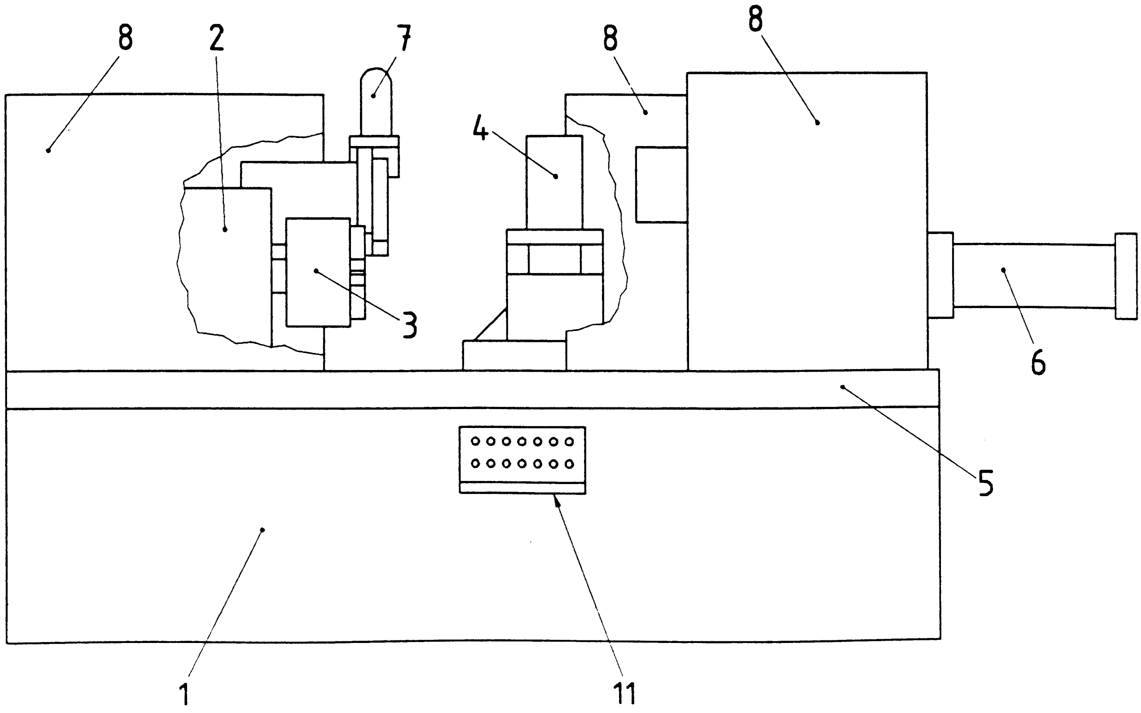
It may be possible to negate some of the above by critical selection of parameters or heat treatment.

4.3 Friction welding machines

4.3.1 General

Friction welding is not positionally sensitive and may 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.



1	Machine frame	7	Flash removal unit
2	Headstock with drive spindle and brake	8	Safety guards
3	Chuck - for rotating component	9	Hydraulic power pack - not shown
4	Clamp - for fixed component	10	Electrical control cabinet - not shown
5	Machine slides (tie-bars)	11	Machine control panel
6	Force actuator		

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, brake 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, will undertake a controlled welding cycle without intervention from the operator and will incorporate at least the following operational cycle:

– initiation of a sequence which will bring 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 may or may not be done automatically, 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 conditions

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 overhang 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 overhang of each is equal, unless the difference in composition or size of the two components makes it desirable for them to have different overhangs, 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.

NOTE: 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 may 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 may 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

6.2.1 Identification of the manufacturer

– Unique identification.

6.2.2 Identification of the WPS

– Alphanumeric designation (reference code) related to a specific friction welding machine.

6.3 Information related to the material

6.3.1 Material type

– Identification of the material, preferably by reference to an appropriate standard.

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

6.3.2 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

6.5.1 Joint design

A sketch of the joint design showing position of weld(s), details and tolerances may be made.

6.5.2 Preparation of components

Selected method of surface preparation, as necessary (e. g. sawing, turning).

6.5.3 Fixtures

– The methods to be used;
– details of fixtures and backstops.

6.6 Optional devices

E.g. 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 standard 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 provisions in this section unless more severe tests are required by the design specification or by other standards when these shall apply.

7.2.2 Preliminary welding procedure specification (pWPS)

The preliminary welding procedure specification shall be prepared in accordance with clause 6 of the standard.

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.

7.2.4 Specification for test specimens

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

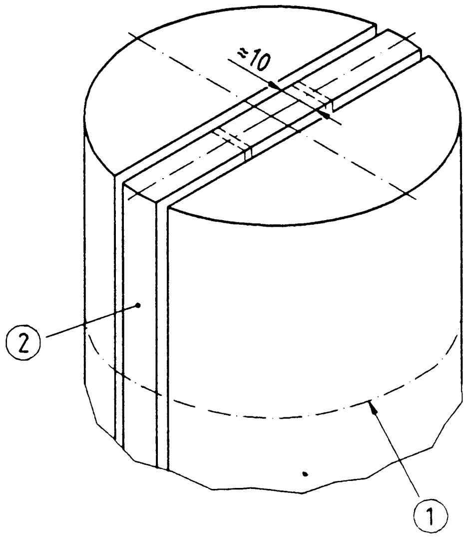
The weld shall be dressed flush, unless otherwise agreed by the test specification, having a surface finish that does not affect the result. When components of differing sections are welded together, the larger section shall be reduced to equal that of the smaller after welding.

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

Dimensions in millimetres

Guide values:

Thickness: nominal 10 mm
Width: ≥ 25 mm
Length: depending on the component



1 is the position of weld interface
2 is the test specimen for bending

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 will result 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 effect 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 effect 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 follows:

– for tubes of outside diameter less than 50 mm:

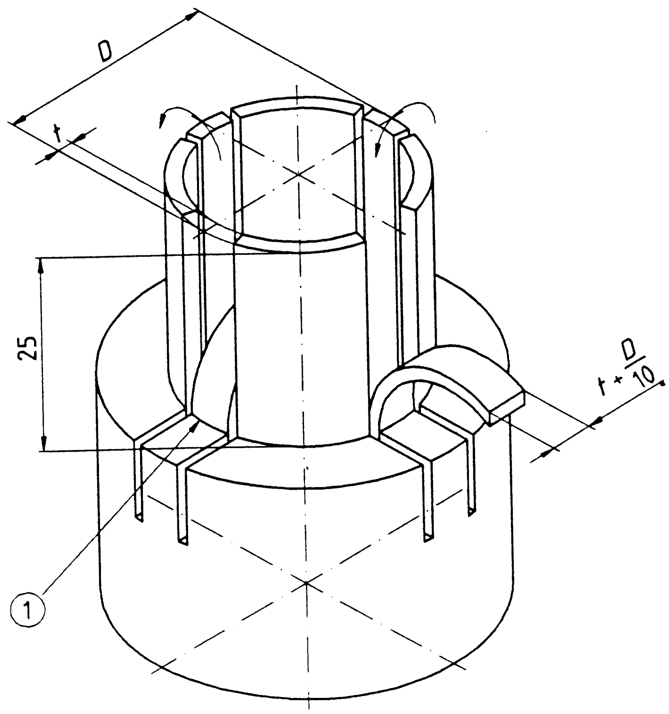
$t + D/10$

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

$t + D/20$

where: t is the wall thickness in mm;
D is the outside diameter of the prepared tube in mm.

Dimensions in millimetres



1 is the 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 has to 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 – above 10 mm to 20 mm – above 20 mm	– 2 inwards and 2 outwards – 2 inwards and 2 outwards or all 4 side face – all 4 side face

NOTE: When making a bend test on a specimen from items from hardenable material a "knee joint effect" will be 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 performe the bend test. Although evaluation procedure may be considered. Also consideration has to be given to surface hardened materials where the hardened area may affect mechanical test results.

7.2.5.2 Alternative tests

Alternative tests may be used in certain instances.

Further examinations and tests see 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 (WPAR)

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 (WPAR).

An example of a recommended WPAR 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 could 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, stopping 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 burnoff period or length. The burnoff 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 burnoff period is terminated.

A.1.3 Stopping phase

The function of the stopping 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 stopping phase is influenced by one or more of the following:

- power of any braking that may be 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. A low forge force may not be sufficient to expel debris and an excessive forge force may 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.

Annex C
(informative)

Material combinations weldable by friction welding

[●] weldable

[ ] little or no experience

PM – powder metallurgy

	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	●																			

NOTE: This schematic diagram gives no information regarding weld quality which is application dependant.

Annex D
(informative)

Guidelines for quality assurance

The level of quality assurance is determinded 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 permissable and non-permissable characteristics and results are to be specified in the test specification.

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

E.1.2 Visual examination

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

- shape and size of the flash;
- axial and angular deviation.

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

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.

EN 1289 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.

EN 1290 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.

prEN 1711 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.

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.: ....
WPAR 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

....
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				

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 standardised terminology.

Table G.1 - Characteristics of friction welded components

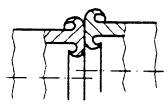
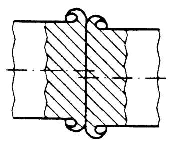
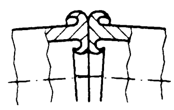
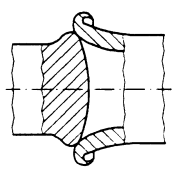
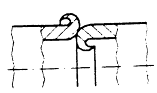
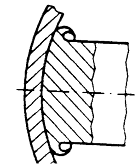
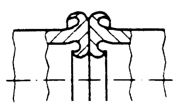
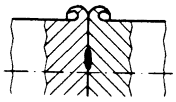
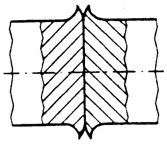
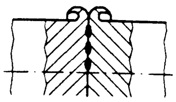
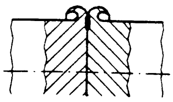
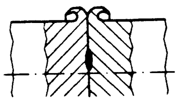
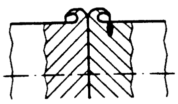
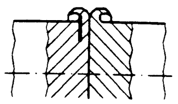
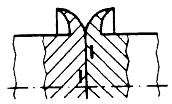
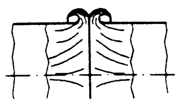
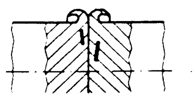
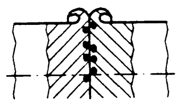
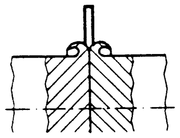
Desig-nation	Explanation	Diagram	Usual test methods	Cause	Remedy	Remarks
1 Shape deviation						
Axial misa-lignment	misalignment of parallel axes of components	 	measurement, visual exami-nation,macro-scopic	clamps, geometrical inaccuracy, overhang too long, poor component preparation, angularity	adjustment 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 examina-tion	clamping length too short, over-hang 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 examina-tion, macroscopic	welding parameters, component geometry, overhang too long, axial misalignment, workpiece preparation, angularity	change	critical mainly when friction welding thin-walled tubes and compo-nents of very dissimilar mate-rials
Deforma-tion of workpieces	undesired change in geometry	examples:  bending  flattening	measurement, visual examina-tion	insufficient support, axial strength too high, overhang too long, tooling wear	adjust clamping, increase rigidity	occurs when welding thin-walled work-pieces
(continued)						

Table G.1 (continued)

Desig-nation	**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 preparation	
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-/micrographs, examination of fracture	component preparation, welding parameters, 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	
	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		

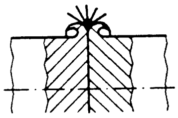
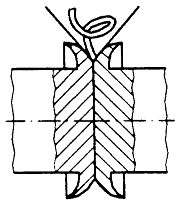
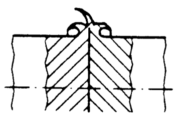
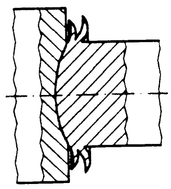
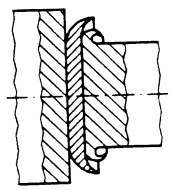
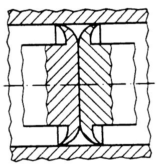
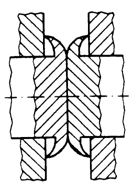
(continued)

Table G.1 (continued)

Desig-nation	Explanation	Diagram	Usual test methods	Cause	Remedy	Remarks
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, overhang 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 1000 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-metalic phases	diffusion of elements		macro-/micrographs	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-/micrographs, ultrasonic test to a certain degree		better homogeneity of material, change weld parameters, e.g. shorten welding time	
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

(continued)

Table G.1 (concluded)

Desig-nation	Explanation	Diagram	Usual test methods	Cause	Remedy	Remarks
Burr	extrusion of material all the way around		visual examina-tion	unknown	unknown	consequences unknown
	material protru-des in a spiral shape at irregular intervals		visual examina-tion	insufficient heat input	increase energy input by increa-sing r.p.m.	
	at regular intervals		visual examina-tion	unknown	unknown	
Secondary flash I	assymetrical welding flash		visual examina-tion	very dissimilar materials or workpieces		for steel stud type welds or components of differing sec-tion; it is good to develop flash from plate or bigger section
Secondary flash II	displacement of welding surfaces			welding parameters	change welding parameters, increase friction force	it is bad if se-condary flash sits on plate (bigger section) and has come from stud (smaller section)
Flash restriction	deforms against tooling	 	visual examina-tion	inadequate overhang and poor tooling	increase overhang and improve tooling	Reduces wel-ding pressures, can increase cooling rate. However can be used to advantage.

Annex H
(informative)

Welding procedure approval record form (WPAR)
Welding procedure approval - Test certificate

No.: ....

Company: ....
....
Component: ....
Job No.: ....
Drawing No.: ....
WPAR 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

....
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:

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ICS 25.160.10

Price based on 33 pages