TECHNICAL REPORT

ISO/TR 10809-2

First edition
2011-04-01

Cast irons —

Part 2: **Welding**

Fontes —

Partie 2: Soudage

Reference number
ISO/TR 10809-2:2011(E)

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Foreword

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

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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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

ISO/TR 10809-2 was prepared by Technical Committee ISO/TC 25, *Cast irons and pig irons*.

ISO/TR 10809 consists of the following parts, under the general title *Cast irons*:

— *Part 1: Materials and properties for design*

— *Part 2: Welding*

Introduction

Cast irons can be successfully welded, see References [4], [9], [10], [16], [17] in the Bibliography. A precondition is that the welding is done professionally and with care.

It is intended that all welding of the different cast iron types and grades with themselves or with other ferrous materials should be done by trained personnel, in accordance with appropriate standards and approved procedures.

Technological advances in welding methods have contributed to a change of attitude with regard to welding iron castings.

The designer needs to understand that the conditions/parameters which might need to be considered if welding is to be carried out by a suitable welding process for either production or repair depend upon

- the cast iron material,
- the expected quality level of the weld,
- the casting shape and size,
- the welding application,
- the welded joint, and
- the filler metal(s), if required.

Advancement of the state-of-the-art in welding of cast iron materials has been incorporated into International and European Standards [1], [2], [3], [5] in the Bibliography.

Economic considerations should be taken into account when deciding on the suitability of welding a casting.

As an important precondition, the weld of the casting or the constructive unit should satisfy the requirements to be agreed at the time of ordering between manufacturer and purchaser.

NOTE Currently, the best knowledge and most experience exist for malleable cast irons and spheroidal graphite cast irons.

This part of ISO/TR 10809 gives design engineers knowledge as to whether or not it is possible to weld the many types and grades of cast iron standardized in a number of international cast iron material standards

Cast irons —

Part 2:
Welding

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

The purpose of this part of ISO/TR 10809 is to assist the design engineer to understand and to acquire knowledge of how the family of cast iron materials can be welded and to utilize this technology to its full advantage in selecting the most appropriate technique for a particular cast iron. Because the application of welding technology and the metallurgical implications of welding are not scientific disciplines normally taught to engineering students, such users often have limited knowledge of the fundamentals underpinning welding technology for cast irons. This part of ISO/TR 10809 explains what can be achieved, what cannot be achieved and why. It is not designed to be a textbook of welding technology. It helps users to select the most appropriate welding process and conditions for a specific application.

This part of ISO/TR 10809 covers production (including finishing and joint welding) and repair welding.

2 Metallurgy

The temperatures which occur during welding dissolve the graphite present in the liquid metallic matrix. Depending on the carbon saturation of the melt and cooling rate of the weld, either martensite and/or ledeburite is formed. In the case of ledeburite, it is formed in the molten areas after a very short time interval (≤ 40 ms). Therefore, it is practically impossible to avoid the formation of ledeburite.

Both martensite and ledeburite are very hard and brittle. They prevent deformation under load, impede machining of the weld and enhance the formation of welding cracks, unless suitable counter-measures are taken.

With the application of appropriate welding processes (e.g. pressure-welding processes), ledeburite can be removed totally from the welding groove, and the formation of martensite can be avoided by either preheating the welding area or the whole casting. They can be completely removed or minimized if appropriate post-weld annealing procedures are followed. To achieve these conditions, the material-specific interrelationships between the base material and the weld material should be converted into production parameters, so as to allow targeted and process-safe settings for the weld-seam characteristics.

The following major welding parameters/control variables are available.

a) Pre-heat temperature: To avoid martensite formation, the weld area should be pre-heated to temperatures above the start temperature of martensite transformation. Pre-heating will not prevent the formation of ledeburite.

b) Heat input: should be as low as possible during welding.

c) Welding speed: will vary depending upon the welding procedure applied and the chemical composition of the cast iron type and grade.

d) Cooling curve: In principle, the required cooling curve can be determined from the time-transition-temperature (TTT) diagram relevant to the cast iron material. For instance, continuously controlled cooling according to the appropriate TTT diagram can prevent the formation of martensite, e.g. in a flash-welding machine. When manual welding methods are used, the cooling rate is influenced by the selected pre-heating temperature.

e) Welding procedure/welding parameter: for automated procedures.

f) Filler metal: When manual or mechanized welding-arc processes are used, the filler metal is matched against the requirements of the weld or welded joint. This depends upon whether the welding process is carried out with homogeneous, semi-homogeneous or non-homogeneous filler metal. No filler metals are needed for the pressure-welding processes described later in the text.

g) Post-weld heat treatment: Measures can be undertaken to remove undesirable structures, such as:

- martensite which can be removed by a sub-critical anneal (tempering);
- ledeburite which can only be removed by a graphitization anneal at austenitizing temperature.

However, these control parameters are not independent of each other and have to be coordinated with the welding procedure applied.

3 Terms and definitions

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

3.1
production welding
any welding carried out during manufacturing before final delivery to the end user

NOTE Production welding includes finishing welding and joint welding.

3.1.1
finishing welding
production welding carried out in order to ensure the agreed quality of the casting

EXAMPLE Finishing welding is the elimination of discontinuities at the surface, e.g. gas pores, sand/slag inclusions, unacceptable shrinkage cavities or cracks that impair the usability of the casting or substantially disturb the appearance of the casting, and which therefore have to be removed during production and before the casting is delivered to the customer.

3.1.2
joint welding
production welding used to assemble components together as an integral unit

EXAMPLE Joint welding is used when a casting is to be joined to another casting or component, e.g. sheet metal or steel profile, to form a complex constructive unit. Welding is part of the manufacturing process and can either be carried out in the foundry itself or at the facility of the processing subcontractor.

3.2
repair welding
welding carried out after final delivery of the casting to the end user

EXAMPLE A broken machine-column casting is causing substantial downtime and financial loss for the user. It would take too long to procure a new casting and delay production for an unacceptably long time period. Repair welding of the broken casting could solve the problem more quickly and economically.

4 Suitable welding processes

4.1 General

Five classes of welding process are described in the following subclauses:

- arc welding, see 4.3.2, 4.3.3, 4.4.2, 4.4.3, 4.4.4, 4.5, 4.6, 4.8.2;
- beam welding, see 4.7;
- resistance welding, see 4.8.1;
- oxy-acetylene gas welding, see 4.2;
- welding with pressure, see 4.8.1, 4.8.2, 4.8.3.

NOTE ISO 4063[54] categorizes the welding process by a number. In this part of ISO/TR 10809, the number relating to the welding-process follows the title of the clause.

4.2 Oxy-acetylene gas welding (311)

The oxy-acetylene gas welding process uses a manually operated flame as the heat source. The flame is energized by a gaseous fuel mix of oxygen and acetylene, the oxygen being mixed with the acetylene inside the burner. The flame is characterized by a two-stage combustion process which enhances the welding process, especially that of providing a protective shield against the ambient atmosphere.

Homogeneous welding rods should preferably be used for oxy-acetylene welding with large output burners having a neutral to slightly reduced flame setting. Fluxes designed to give a neutral atmosphere that prevent oxidation and re-dissolve the oxides formed during pre-heating are either integrated into the welding rods as grooves as a covering, or they are added separately. But also non-homogeneous filler metals are utilized. Data on mechanical properties of welds can be found in Reference [8] in the Bibliography.

4.3 Arc welding (1)

4.3.1 General

The process uses electrically generated welding heat with either homogeneous, semi-homogeneous or non-homogeneous filler rods to make the weld.

The electrical arc has a core temperature of between 5 300 K and 6 000 K. The arc is struck between the surface of the component to be welded and the consumable filler rod.

The coating on the electrode has several uses:

- protection against the atmosphere; the droplets of metal in the arc are protected by a cover of slag or protective gas;
- easier ignition of the arc;
- solid arc by ionization of the air column;
- alloying of the weld deposit;
- covering of the weld seam during cooling;
- increasing the deposition rate by adding iron powder;
- modification of the welding characteristic for such properties as current, polarity, weld shape, basicity and amperage.

Manual arc welding is the preferred procedure using covered electrodes (see ISO 1071[2]) with a pure nickel or nickel-iron core wire. Data on mechanical properties can be found in Reference [8] in the Bibliography. For certain applications, Ni-Cu, Cu-Al and Cu-Sn alloys have been used successfully.

The welding parameters chosen should ensure a narrow heat-affected zone with small amounts of hard structure. Interconnected martensitic and/or ledeburitic transition and heat-affected zones are particularly unfavourable as they induce residual stresses in the casting. Island-like distribution induces less stress in the welded area of the casting. Residual stress can be minimized by adopting some or all of the following measures, see Reference [15] in the Bibliography:

- using electrodes with the smallest possible core-wire diameter;
- using the lowest possible welding current to generate a short arc;
- depositing short stringer beads of 20 mm to 30 mm length with a low cross-section;
- allowing sufficient cooling time between the individual beads;
- changing the welding direction between the individual layers;
- holding the electrode vertically.

4.3.2 Metal arc welding with covered electrodes (111)

In order to fill the weld as quickly as possible and to maintain a constant pre-heating temperature as far as possible, metal arc welding with large-diameter covered electrodes in conjunction with a high current (up to 1 500 A) is chosen. For welding spheroidal graphite cast irons, the covered electrodes can consist of a cored rod of spheroidal graphite cast iron or steel. When a steel rod is used, carbon and silicon as well as elements required for spheroidal graphite formation, such as magnesium, cerium or other rare earths are added from the weld rod coating. Spheroidal graphite cast-iron rods used for oxy-acetylene welding can also be used. Since the magnesium contained in these rods, which is required for spheroidization, is prone to evaporate in the arc, covered electrodes or unalloyed core wires are preferred to reduce the susceptibility to graphite degeneration. An overview of the requirements for welding materials and the design of welding rods and covered electrodes can be found in Reference [2] in the Bibliography.

4.3.3 Self-shielded tubular-cored arc welding (114)

Due to the outside cover and the length of the electrodes, limits have to be set for manual metal arc welding concerning the degree of mechanization and, with it, the possible improved efficiency. Continuously fed electrodes offer essential increased efficiency.

Suitable welding processes are

- gas-shielded metal arc welding with bare electrodes, and
- submerged arc welding with bare electrodes.

The following self-shielded tubular-cored electrodes are the state-of-the-art:

- self-shielded tubular-cored wire electrodes used with or without gas protection. When welding without gas protection, the slag formers are positioned in the middle of the electrode wire. An excess of deoxidizer should be present;
- gas-shielded (CO_2) with bare wire electrodes.

Metal arc welding with flux-cored wire electrodes is gaining more and more in importance for economic reasons, because the process can be automated. The process has a high weld-metal recovery and provides numerous alloying possibilities. Since high pre-heating temperatures can cause thermal distortion, self-shielding flux-cored wires are used instead of shielding gas.

4.4 Gas-shielded metal arc welding (13/14)

4.4.1 General

The TIG (Tungsten Inert Gas), MIG (Metal Inert Gas) and MAG (Metal Active Gas) processes have special advantages by welding with non-homogeneous filler metal, due to the high energy density of their gas-shielded arcs and the associated narrow heat-affected zone.

4.4.2 Tungsten inert gas welding — (TIG welding) (141)

The arc burns between the unconsumed tungsten electrode and the work piece under the protection of an inert gas. This protective gas flows through a gas jet and protects the electrode and the weld against air ingress. Inert gases, such as Argon (Ar) and Helium (He), or mixtures of both gases, protect the tungsten electrode. Oxidizing protection gases, e.g. O_2 or CO_2, cannot be used. However, when welding certain metals, small percentages of H_2 are sometimes added. The process lends itself to part or full mechanization with or without filler metal welding. Welding rods or wire are normally added with the power off.

4.4.3 Metal inert gas welding — (MIG welding) (131/132/133)

As a general rule, the arc burns between a positive consumable welding wire and the work piece under a streaming inert gas inside an inert gas jacket. The protection gases are the same as those used for TIG welding. Inert gases, even with the high temperature of the arc, do not react with the weld. MIG welding is suitable for the welding of Aluminium (Al) and Magnesium (Mg) and their alloys.

The MIG/MAG processes can be used for joint welding, and when they are automated, it is possible to use them for large-scale joint-welding production. The MIG/MAG processes are increasingly used for hard facing (repair welding), finishing welding and general repair welding. By reducing the heat input through the adoption of short-arc and impulse technology, extremely narrow heat-affected zones result, with improved mechanical properties as shown in Reference [9] in the Bibliography. The main shielding gas used is argon. Today, only small amounts of CO_2 are recommended for MAG welding. A higher CO_2 content is considered problematic with regard to its oxidizing effect on magnesium and, as a possible consequence, the degeneration of graphite in cast iron.

4.4.4 Metal active gas welding — (MAG welding) (135/136/138)

Compared to MIG welding, the only difference in the welding process is that the inert gas is replaced by active gases such as CO_2, mixtures of either Ar and CO_2 or Ar, CO_2 and O_2. The same welding equipment is used for both MIG and MAG welding. The arc burns with the protection of an active gas between the consumable welding wire and the work piece. When using equal current and voltage, the protection gases have an effect on the arc shape, the length of the arc and the upper and lower welding beads.

Figure 1 illustrates the bending fatigue strength of un-welded and welded ferritic (left picture) and pearlitic (right picture) spheroidal graphite cast iron. These results are quite well in accordance with the results of blackheart malleable cast irons of the same strength category (References [10], [11] in the Bibliography).

4.5 Submerged arc welding (12)

Submerged arc welding is a masked arc welding process. The arc burns between the consumable wire electrode and the work piece. The arc is protected by a loosely (not fixed) filled granular, easily fluxed powder. Sparks and spatter are prevented by this technique. The powder protects the weld pool against air ingress, avoids abrupt cooling, shapes the weld and assists gas emission from the weld metal. It also has a metallurgical influence on the chemical composition of the weld metal.

Submerged arc welding, electro-slag welding with solid or flux-cored wire, cast welding or liquid metal welding are mainly used for repair welding of large castings.

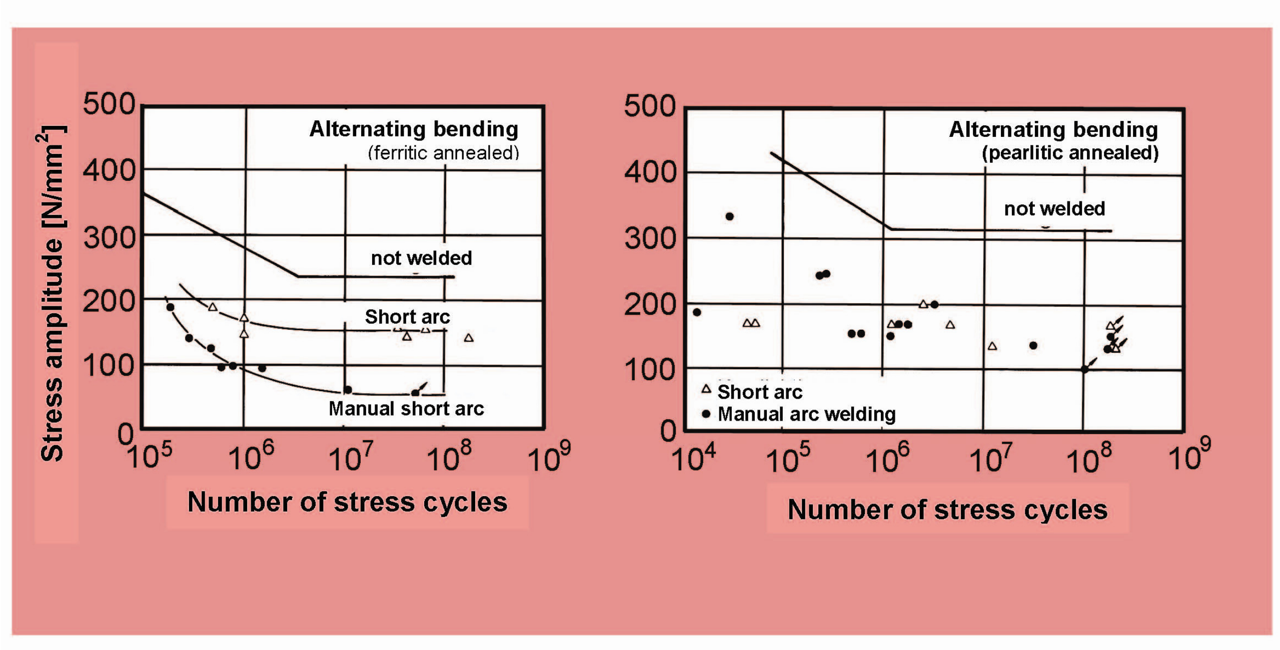


Figure 1 — Bending fatigue strength of un-welded and welded ferritic (left) and pearlitic (right) spheroidal graphite cast iron

Figure 1 is reproduced by permission of Bundesverband der Deutschen Giesserei-Industrie, Dusseldorf.

4.6 Plasma arc welding with or without filler metal (15)

Plasma welding is operated by a heavily heated gas consisting of molecules, atoms, ions and electrons. It is entirely electrically neutral.

Two different arc arrangements are used, an auxiliary arc and an assigned arc. The auxiliary arc is used to ignite the assigned arc. The auxiliary arc is induced by high-frequency current. If the assigned arc is ignited then the auxiliary arc extinguishes. The assigned arc burns between a non-consumptive thoriated tungsten electrode and the work piece. A water-cooled strangling copper injector is the anode and a Ti-electrode is the cathode. The plasma gas is blown into the annulus collector between the anode and the cathode. The Cu-injector effects a lateral contraction of the arc, thus an improvement of power density and accordingly an increase of temperature of the plasma beam. Adjustments allow the process to be used for either welding or cutting.

For plasma arc joint welding, in addition to the plasma gas, a second gas stream (99,95 % Ar) is used in order to protect the weld pool against atmospheric interference.

Most plasma arc welding equipment uses a third gas stream, the focussing gas (Ar + He, Ar + H_2, Ar + N_2) for additional compressing of the plasma stream outside the strangling injector.

Plasma welding with or without filler metal is mostly an application-orientated procedure, e.g. for pipe joints (see Figure 2).

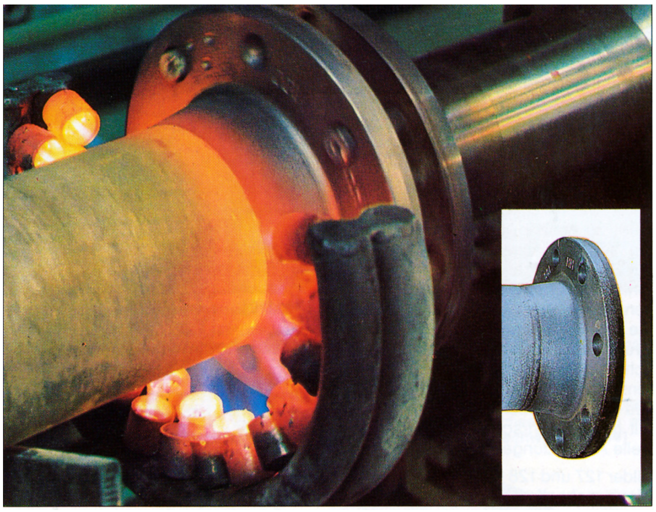


Figure 2 — Plasma welded joint between a centrifugal casting tube and a spheroidal graphite cast iron (JS) flange

Figure 2 is reproduced by permission of Bundesverband der Deutschen Giesserei-Industrie, Dusseldorf.

4.7 Electron beam welding (511)

When energy conservation is sought, electron beam welding should be considered as an alternative welding method (Reference [10] in the Bibliography). Electron beam welding has a very favourable heat input. Welding without filler metal showed unsatisfactory results. However, by adding a nickel inlay, the hardened zones in the area of parent metal were reduced to a minimum. Due to the procedural complexity, electron beam welding will very probably remain limited to certain special applications.

4.8 Pressure welding processes (4)

4.8.1 Flash welding (24)

Pressure welding processes use the application of heat and pressure to give macro-deformation and coalescence of the base material. Flash welding is a resistance pressure-welding process. The welding heat is generated by resistance heating directly in the welding unit by induced current. The parts are repeatedly pressed together, such that the contact faces are heated by the flashing (sometimes referred to as arcing) of the welding current. The process is reversed (repeated) until the energy at the contact faces is sufficient to achieve continuous flashing.

During the flashing phase, “fusing contacts” develop where the ends of the electrically charged parts are brought together. The extremely high current created in the transition zone quickly heats and melts the metal. The high resistance caused by insufficient compressing of the contact faces increases the deposition rate of the weld. Vapour pressure builds up on the weld surface as a result of metal evaporating in some areas. Due to vapour pressure, liquid metal is thrown out of the welding gap, creating a “shielding gas atmosphere” that keeps the atmospheric oxygen away from the weld. The flashing process is continued until the required welding temperature is reached. Then the machine control starts the upsetting process, followed by switching off the electric current.

Large, thick-walled castings are usually welded after pre-heating. Thin-walled castings do not normally require “reversing”. The process is then called flash welding without pre-heating, or “cold flash welding”.

Modern welding machines can provide a resistance post-weld heat treatment while the parts are still in the machine, thus avoiding intermediate cooling with the potential risk of creating martensitic structures prone to cracks.

The flash-welding process is divided into the following steps:

— initial flashing to produce parallel surfaces;

— flashing to generate sufficient heat for the upsetting operation;

— upsetting to compress two surfaces to form the joint and press out ledeburite from the weld zone;

— controlled cooling, post-weld, to prevent the formation of martensite and to produce the required structure (References [12], [13], [14] and [40] in the Bibliography).

Figures 12, 14 and 15 illustrate the process sequences and the process monitoring (see 6.1.2.2).

4.8.2 Magnetically impelled arc welding (185)

Welding with a magnetically impelled arc, sometimes referred to as Magnetarc™ welding, is an arc pressure-welding process that makes use of the fact that an arc can be deflected in various directions by a controlled magnetic field. Depending on the direction and intensity of the magnetic field, the arc can be rotated around its own axis, or programmed to take an elliptic shape of varying current density. In most cases, the electric arc moves between two tubes.

Welding is carried out with fully mechanized or automated welding equipment. The work pieces are centred and clamped in the machine, and the arc is struck as soon as the two faces to be joined touch. The arc is then rotated between the abutting faces with increasing speed, thereby melting them. Direct current is used for this welding process. The rotational speed is between 30 m/s and 150 m/s, depending on the strength of current, magnetic field and shielding gas used, which equals a rotational frequency of between 200 Hz and 2 000 Hz. After a predetermined period of time, the two components are pressed together, and then the welding current is switched off.

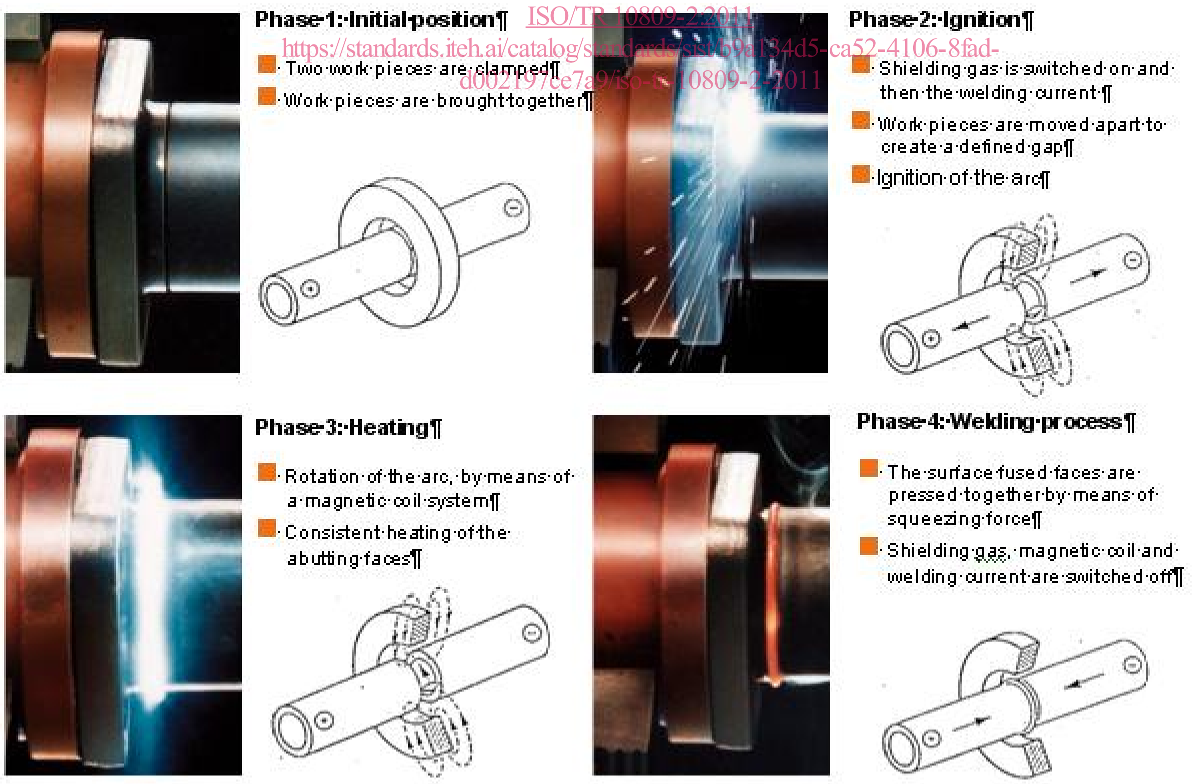


Figure 3 — Successive process steps of magnetically impelled arc welding

Figure 3 is reproduced by permission of KUKA Systems GmbH Industrial Solutions, Augsburg.

Examples of the ranges of the process parameters:

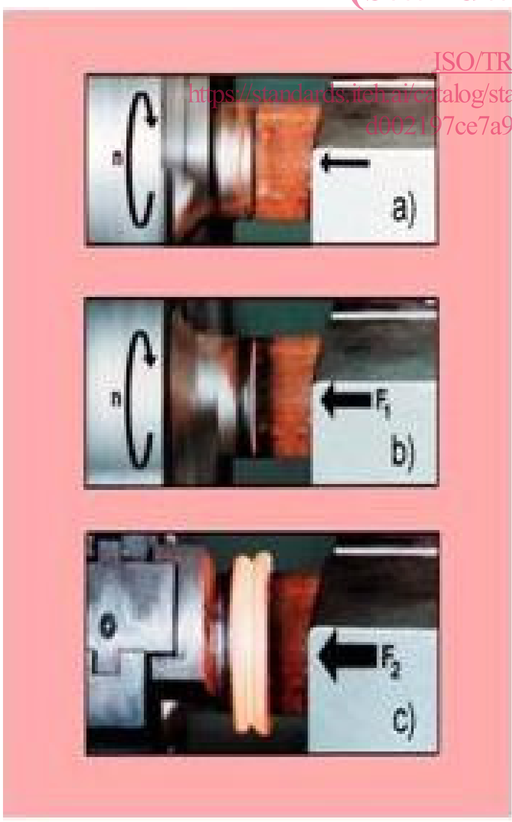
- Strength of current: 200 A to 1 200 A
- Welding time: 0,3 s to 5 s
- Length of arc: 1,5 mm to 3 mm
- Upsetting force: 0,5 kN to 450 kN
- Magnetic field: 100 G to 500 G
- Shielding gas: Mainly CO_2

4.8.3 Friction welding (42)

Friction welding belongs to the group of hot pressure-welding processes. Heat generated by friction due to the relative motion of the contact faces allows joining under a compressive load. Here a distinction is necessary between conventional- and inertia-friction welding. During conventional-friction welding, powerful electric motors accelerate and stop the rotating component. During inertia-friction welding, the applied thermal energy is supplied by the mass and speed of the flywheel.

Friction welding can be successfully achieved by using the right combination and sequence of contact pressure and/or number of revolutions during welding. State-of-the-art control systems are used to provide a practically unlimited choice of pressure/speed curves. Changes in pressure or speed can be planned continuously or step by step. Typically, speeds range from approximately 500 to 3 000 r/min, with pressures varying between 20 N/mm^2 and 100 N/mm^2. When the joining faces have been heated sufficiently, the rotational movement of the friction spindle is decelerated abruptly to start the upsetting phase, and the two parts to be joined are forged together. Upsetting may be effected either while the spindle is still rotating with a defined speed, or into the spindle. The upsetting pressures applied are generally above the friction pressures needed to create the friction.

Figure 4 shows the successive process steps of friction welding.



Phase 1: Two pieces are clamped, rotation of one work piece

b) Phase 2: Heating: Two work pieces are pressed together with force F (friction force) Rotation n and force F_1 generate friction; the surfaces to be welded are heated

c) Phase 3: Welding: Rotation of the work piece is slowed down (selectable deceleration time), joining by increased force F_2, upsetting force

Figure 4 — Process phases of friction welding

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