SLOVENSKI STANDARD
SIST EN 1011-6:2006

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Varjenje ï Priporoļ ila za varjenje kovinskih materialov ï 6. del: Lasersko varjenje

Welding - Recommendation for welding of metallic materials - Part 6: Laser beam welding

Schweißen - Empfehlungen zum Schweißen metallischer Werkstoffen - Teil 6: Laserstrahlschweißen

Soudage - Recommandations pour le soudage des matériaux métalliques - Partie 6: Soudage par faisceau laser

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This European Standard was approved by CEN on 28 November 2005.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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Foreword

This European Standard (EN 1011-6:2005) has been prepared by Technical Committee CEN/TC 121 “Welding”, the secretariat of which is held by DIN.

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of an identical text or by endorsement, at the latest by June 2006, and conflicting national standards shall be withdrawn at the latest by June 2006.

This standard is composed of the following parts:

— Part 1: General guidance for arc welding;

— Part 2: Arc welding of ferritic steels;

— Part 3: Arc welding of stainless steels;

— Part 4: Arc welding of aluminium and aluminium alloys;

— Part 5: Welding of clad steel;

— Part 6: Laser beam welding;

— Part 7: Electron beam welding;

— Part 8: Welding of cast irons (prepared by CEN/TC 190).

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

Introduction

This standard is being issued in several parts in order that it can be extended to cover the different types of metallic materials that will be produced to all European Standards for weldable metallic materials.

When this European Standard is referenced for contractual purposes the ordering authority or contracting parties should state the need for compliance with the relevant parts of this standard and such other annexes as are appropriate.

This European Standard gives general guidance for the satisfactory production and control of welding and associated processes and details of some of the possible detrimental phenomena that can occur, with advice on methods by which they can be avoided. It is generally applicable to laser beam processing of metallic materials and also to some extent for non-metallic materials. It is appropriate regardless of the type of fabrication involved, although the relevant product standard, structural code or the design specification can have additional requirements. Permissible design stresses, methods of testing and inspection levels are not included because they depend on the service conditions of the fabrication. These details should be obtained from the relevant application standard or by agreement between the contracting parties.

It has been assumed in the drafting of the standard that the execution of its provisions is entrusted to appropriately qualified, experienced and trained personnel.

1 Scope

This European Standard gives general guidance for laser beam welding and associated processes of metallic materials in all forms of product (e.g. cast, wrought, extruded, forged).

NOTE Some guidance on laser beam cutting, drilling, surface treatment and cladding is given in Annex F.

2 Normative references

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

EN ISO 3834-2, *Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements (ISO 3834-2:2005)*

EN ISO 3834-5, *Quality requirements for fusion welding of metallic materials - Part 5: Documents with which it is necessary to confirm to claim conformity to the quality requirements of ISO 3834-2, ISO 3834-3 or ISO 3834-4 (ISO 3834-5:2005)*

EN ISO 11145:2001, *Optics and optical instruments — Lasers and laser-related equipment — Vocabulary and symbols (ISO 11145:2001)*

EN ISO 15609-4, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 4: Laser beam welding (ISO 15609-4:2004)*

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN ISO 11145:2001 apply.

4 Health and safety and protection of the environment

A general checklist on protection of the environment in welding and allied processes is in preparation by CEN/TC 121. It will cover laser applications.

Laser beam processing introduces additional hazards over and above those normally experienced in arc welding. Specialist advice should be sought, see e.g. EN 60825-1 and EN ISO 11553-1.

Guidance for safety aspects related to the application of industrial robots for manipulation of the focussing devices and/or the components to be welded can be found in EN 775.

5 Quality requirements

Laser beam welding is a complex process needing detailed process control. All processing is performed under numerical control necessitating programming of each single operation. The application has to be controlled at a level compatible with EN ISO 3834-2 and EN ISO 3834-5.

NOTE This does not entail a requirement for certification but the process control should operate in accordance with EN ISO 3834-2 and EN ISO 3834-5.

It is a condition for efficient process control that quality requirements for joint geometry and other relevant requirements have been specified prior to start of fabrication. A number of European Standards specify joint geometry and relevant quality criteria and can be used for reference, as appropriate:

Table 1 — Quality criteria

Requirements and tolerances	Standard no.
Quality requirements to beam welded joints	EN ISO 13919-1 EN ISO 13919-2
Quality requirements for cut surfaces	EN ISO 9013
General tolerances	EN ISO 13920
General requirements	EN ISO 3834-2 and EN ISO 3834-5 specify provisions for information and items to be agreed and specified prior to the start of fabrication. EN 1011-1:1998, Annex A can be used as a guide in case EN ISO 3834-2 and EN ISO 3834-5 are not called for.

6 Equipment

6.1 General

Information about particular equipment for laser beam processing has to be found in information from the supplier. A number of textbooks and a large number of articles provide background information. Annex A provides some very general information on principles and techniques. Annex B provides general information on the properties of laser beams.

6.2 Provisions for acceptance testing

Provisions for acceptance of laser beam equipment are found in the following standards, see Table 2.

Table 2 — Provisions for acceptance testing

Type of equipment	Standard no.
CO_2 laser beam equipment	EN ISO 15616-1, EN ISO 15616-2 and/or EN ISO 15616-3
Nd:YAG laser equipment	EN ISO 22827-1, EN ISO 22827-2

6.3 Provisions for maintenance and calibration

Provisions for maintenance are not standardised. The supplier's manuals have to be consulted. Principles for calibration, verification and validation and minimum requirements are specified in EN ISO 17662.

7 Qualification of welding personnel

The requirements for the qualification of personnel for fully mechanised and automatic welding and allied processes are laid down in EN 1418. Among the different procedures specified in this European Standard, the functional test is particularly suitable as a basis for qualification of personnel responsible for the operation and set-up of laser beam processing. In a functional test, the operator or setter demonstrates his/her knowledge of working with a procedure specification and of setting, supervising and checking the laser beam processing machine.

8 Welding procedure specification

All details for the laser beam welding of components are to be recorded in a welding procedure specification (WPS) according to EN ISO 15609-4. Procedure specification for cutting, drilling, surface treatment and cladding are not standardised. EN ISO 15609-4 can, however, give some guidance.

9 Welding procedure test

Formal qualification of all procedures for laser processing is recommended for all applications and required for many applications. Qualification of procedures for laser beam welding (when required) can be performed by procedure testing, see EN ISO 15614-11. Qualification by pre-production testing can also be relevant, however, see EN ISO 15613. Qualification by pre-production testing is common practice for cutting, drilling and surface treatment. EN ISO 15613 can give some guidance.

Qualification of procedures for laser beam welding for cladding (when required) can be performed by procedure testing, see prEN ISO 15614-7. Qualification by pre-production testing can also be relevant, however, see EN ISO 15613.

10 Consumables

10.1 Filler metals

Filler metals are used for laser beam cladding and sometimes for laser beam welding. The main problem in regard to filler metals for laser applications is that the market for such filler metals is rather small and that dedicated standards for filler metals for laser applications do not exist. The usual form of delivery is solid cylindrical wires but powders can also be used, in particular for cladding. What is commercially available is:

— wires marketed as consumables for gas shielded metal arc welding and tungsten inert gas welding. However, it should be noted that metal cored tubular wires might also be suitable. Small-scale (experimental) production of tubular wires can even be feasible for special applications. Relevant standards are EN 440, EN 758, EN 1668, EN 12070, EN 12071, EN 12072, EN 12073, EN 12534, EN 12535, EN 14640, EN ISO 18273, EN ISO 18274;

— wires marketed as consumables for thermal spraying. The usual form of delivery is solid cylindrical wires which are standardised in EN ISO 14919;

— powders for thermal spraying are standardised in EN 1274;

— powders for powder metallurgy.

10.2 Gases

Gases are used for shielding and plasma suppressing in laser beam welding, as cutting assists gas in laser beam cutting, for shielding in laser beam cladding, drilling and marking. Further, CO_2 lasers may need a continuous supply of laser gas.

The only relevant standard is EN 439. This standard is, however, not adequate for all gases used for laser beam processing. Careful specification of composition, tolerances etc. is necessary for all non-standardised gases, when ordering.

11 Design

11.1 Overall design of structure or product

The main consideration is to ensure that all joints are accessible. It can be an advantage that the focussing head can be some distance from the surface of the joint. However, when shielding gas or plasma suppression jets are used, these nozzles have to be placed close to the surface. Application of sensors augment the requirements for accessibility.

11.2 Joint design

Joint design is, of course, relevant for laser beam welding. The default joint is a normal square butt weld in a butt joint. T joints are welded similarly but full penetration may not be necessary. Overlap joints are used for spot welding.

Laser beam welding can accomplish welding of components to tight tolerances. It is a condition, however, that either the fixtures hold the parts very accurately or that the joints are "self-positioning".

Laser beam welding with root backing can be employed if spatter and undercut are to be avoided.

For axial circular welds on components with narrow dimensional tolerances, a press fit like H7/r6 to H7/n6 (EN 20286-2) is recommended. For circular welds with a clearance fit tacking is essential.

11.3 Joint preparation

The quality of laser beam welding relies on accuracy and cleanliness of the joint preparation. Joints can be prepared by machining or cutting. Attention should be paid to the resulting surface condition. Cleaning of weld joint surfaces should be carried out if they are contaminated by oxides, oil, grease, coolant and paint.

The specific cleaning method used will be dependent on the material type, component size and the quality requirements as well as the operational circumstances. The following treatments can be used:

— manual degreasing with a solvent;

— cleaning in a closed solvent vapour unit or in an ultrasonic bath;

— pre-treatment by steam cleaning with a slightly alkaline additive, following by drying;

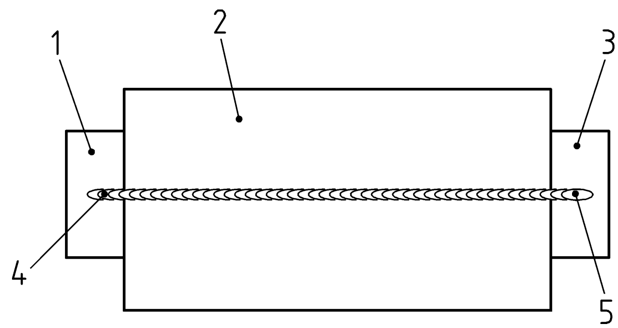
— acid pickling neutralisation, washing in distilled water, drying, short-term storage;

— mechanical cleaning by grinding, brushing etc.;

— primers and similar layers on steel plates can be burnt away by de-focussing the laser beam and move it along the joint prior to welding. Very high speeds of in excess of 100 mm/sec can be used during this treatment.

Where components have surface layers produced by carburising, anodising, cadmium plating, nitriding, phosphating, galvanising etc. these layers usually have to be removed, preferentially by machining of the surface in the weld joint region.

If the component cannot be machined in the weld start and finish regions to remove the end crater, run-on or run-off plates should be used (see Figure 1). These run-on/ run-off plates also suppress heat accumulation at the work piece ends. The run-on/run-off plates should be attached to the work piece by clamping or welding to achieve good thermal contact and will be removed subsequently.



Key

1 Run-on plate
2 Work piece
3 Run-off plate
4 Start of weld
5 End of weld

Figure 1 — Work piece with run-on and run-off plate for separating the weld start and weld end

12 Laser beam welding

12.1 Characteristics

12.1.1 Modes

Laser beam welding is a fusion welding process and the joint is characterised by heat affected zones in the parts, joined by weld metal.

Laser beam welding is often performed as keyhole mode welding. Keyhole mode welding requires a beam with a high power density, able to vaporise the material at the point of interaction. The beam then is able to create (by the vapour pressure) a deep cavity, roughly cylindrical in shape. The walls of the cavity are covered by molten material. When the process is under control, the cavity is propagated with the beam along the joint. Heat and material propagation is essentially two-dimensional. The material melts at the front of the cavity and moves to the trailing edge, where it solidifies, creating the weld metal. A small proportion of the material evaporates or is ejected as spatter and this part of the material is transported in the direction along the axis of the beam. Keyhole mode welding is the usual mode for full and partial penetration butt welds in thick materials.

Another mode is conduction mode welding. In this mode, the intensity of the beam is insufficient to create a keyhole and the heat distribution becomes similar to the heat distribution in arc welding. Conduction mode welding occurs when the beam (of low intensity) is de-focussed or oscillated. Conduction mode welding can result in a three-dimensional heat distribution and the weld cross section is then approximately circular with a width at the surface approximately 2 times the depth of penetration. However, the heat input can be spread over a wider area resulting in a weld with a width larger that 2 times the depth of penetration. A similar technique is used for laser beam cladding where penetration usually is minimised.

In spot welding, the focussing head is kept stationary in relation to the parent material during welding. Welding time for each spot can be measured in milliseconds. Pulsed lasers are commonly used for this purpose. The resulting weld profile is usually intermediate between conduction and keyhole welds.

12.1.2 Energy transfer

The energy is transferred from the laser beam into the base material where it melts the material and creates the keyhole (in the keyhole mode). Energy transfer is influenced primarily by two factors:

— reflection of (a part of) the beam energy from the surface of the base material and liquid weld material;

— creation of a plume of vaporised elements and/or of a plasma cloud (CO_2 laser).

Laser beams are reflected from the surface of materials. The proportion of the energy reflected depends on the surface condition (at the microscopic level), e.g. the surface roughness and also the surface temperature. The proportion reflected can be very high, close to 90 % for polished materials and wavelength above 1 µm at room temperature. The proportion is much lower, below 50 % for shorter wavelength and less reflective surfaces. However, if the beam has enough power to establish a keyhole, reflection becomes of minor importance. Consideration of the reflectivity of the material has become less important with the general availability of high power and high beam quality lasers. When reflectivity causes problems this can result in the process becoming unstable and the keyhole not established locally where for some reason a higher percentage of the beam energy is reflected.

Laser beam welding is usually accompanied by vaporisation of part of the base material. This results in a plume of vapour above the keyhole. High power CO_2 lasers induce such high temperatures that at least a part of the plume is ionised and a cloud of plasma is created in and above the joint (the keyhole). The plasma cloud can attenuate the beam and the usual precaution is to apply a jet of helium, blowing the plasma away.

Helium is the preferred gas for plasma suppression. However, other gases such as N_2 or Ar have been used on an experimental basis. The plasma cannot be entirely suppressed, but welding appears to be feasible none the less.

Vaporisation affects the various chemical constituents of the base material selectively. Components with a high vapour pressure will vaporise more readily. The weld metal will consequently be depleted in such components compared to the base material.

12.1.3 Pulsed beam welding

Pulsed beam welding can be used for spot welding. The high peak power in pulsed lasers can for certain applications be used for establishment of keyhole mode welds in comparatively thick materials. However, the welding speed is less than for a powerful laser having a continuous output.

12.1.4 Beam oscillation

Oscillation of the beam can be used to establish a wider weld profile and can be beneficial where gaps have to be bridged. The augmented welded cross section is accompanied by diminished cooling rates.

12.1.5 Ramping

The numerical control of laser beam power sources usually permits ramping (slope-up and slope-down) which – together with focus control – can be used to obtain satisfactory welds in the start and stop positions. This is of course very important for welding of circumferential and planetary welds.

12.1.6 Beam focussing

The laser beam is usually focussed at or near the surface of the base material.

12.1.7 Gas shielding

Some gas shielding is needed for most applications. The weld pool, the hot part of the weld immediately behind the weld pool and the underside (for full penetration welding) may have to be protected. Gas nozzles of a suitable design should be used. The need for shielding and the type of shielding gas to be used depends on the material welded. Sufficient shielding of all hot parts is of key importance e.g. when welding stainless steels in order to maintain good resistance to corrosion. Full penetration welds in mild steel can, however,