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Destructive tests on welds in metallic materials — Hot cracking tests for weldments — Arc welding processes —

Part 1: General

Essais destructifs des soudures sur matériaux métalliques — Essais de fissuration à chaud des assemblages soudés — Procédés de soudage à l'arc —

Partie 1: Généralités

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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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.

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ISO 17641-1 was prepared by the European Committee for Standardization (CEN) in collaboration with Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 5, *Testing and inspection of welds*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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

ISO 17641 consists of the following parts, under the general title *Destructive tests on welds in metallic materials — Hot cracking tests for weldments — Arc welding processes*:

— *Part 1: General*

— *Part 2: Self-restraint tests*

— *Part 3: Externally loaded tests* [Technical Report]

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Foreword

This document (EN ISO 17641-1:2004) has been prepared by Technical Committee CEN/TC 121 “Welding”, the secretariat of which is held by DIN, 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of an identical text or by endorsement, at the latest by February 2005, and conflicting national standards shall be withdrawn at the latest by February 2005.

EN ISO 17641 consists of the following parts, under the general title *Destructive tests on welds in metallic materials – Hot cracking tests for weldments – Arc welding processes:*

-Part 1: General
-Part 2: Self-restraint tests
-Part 3: Externally loaded tests[1]

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.

[1] Part 3 will be published as a Technical Report with the same general title.

1 Scope

This standard gives an introduction to the fundamentals of hot cracking in weld metals and parent alloys, and briefly describes the tests available for arc welding processes.

— Part 2: Self restraint tests - specifies the tests which should be used to assess the susceptibility to hot cracking of weld metals. The strains to cause cracking are provided by the restraint of the weldment.

— Part 3: Externally loaded tests - describes the tests which can be used to assess the susceptibility to hot cracking of parent alloys and weld metals. The strains to cause cracking are provided by external loading on the test specimen.

NOTE The tests in part 3 require the use of non-standardised proprietary equipment and different laboratories use various procedures, test conditions and specimen sizes, therefore reproducibility within a given laboratory is usually good but differences between laboratories are sometimes found.

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 ISO 17641-2:2004, *Destructive tests on welds in metallic materials - Hot cracking tests for weldments - Arc welding processes - Part 2: Self-restraint tests (ISO 17641-2:2004).*

prCEN ISO/TR 17641-3:2003, *Destructive tests on welds in metallic materials - Hot cracking tests for weldments - Arc welding processes - Part 3: Externally loaded tests (ISO/DTR 17641-3:2003).*

3 Terms and definitions

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

3.1
hot cracks
material separations occurring at high temperatures along the grain boundaries (dendrite boundaries) when the level of strain and the strain rate exceed a certain level

NOTE Small cracks visible only at magnifications greater than X50, are often described as microcracks.

3.1.1
solidification cracks
hot cracks formed during solidification from the liquid phase of weld metals

NOTE They usually extend up to the surface of the weld metal, but sometimes can be subsurface.

3.1.2
liquation cracks
hot cracks formed by liquation of the heat affected zone (HAZ) of the parent material or in multipass welds where weld metal is reheated by subsequent weld beads

3.1.3
ductility dip cracks
hot cracks formed during welding by a reduction in hot ductility. As with liquation cracks they can occur in the HAZ of the parent material or in multi-pass welds

3.2
self restraint tests
tests where specimen loading is produced by strains developed during welding of a restrained weldment

3.3
externally loaded tests
tests where strains are developed in the specimen by the application of external loads in specific test equipment

4 Symbols, designations and units

For the purposes of this European Standard, the symbols and units given in Table 1 apply.

Table 1 – Symbols, designations and units

Symbol	Designation	Unit
$MSI_{(TT)}$	Microcracks sensitivity indicator (tensile test) [a]	mm/mm^2
$MSI_{(LBT)}$	Microcrack sensitivity indicator (longitudinal bend test) [b]	mm/mm^2
L_{tot}	Total length of all detected hot cracks	mm
V_{crit}	Critical strain to form the first hot crack	mm/s
BTR	Brittle temperature range, i.e. difference between NST and DTR (see prCEN ISO/TR 17641-3:2003, Figure 2)	K
[a] $MSI = L_{MF}/L_o \times d \times \pi$ [b] $MSI = L_{MF}/b \times l_o$		

5 Fundamentals of hot cracking

Hot cracks are produced in the weld metal and in the HAZ of parent materials when the strains developed during cooling of a welded joint, or imposed externally, exceed the ductility of a particular part of the joint. They range in size from very small liquation cracks (<1 mm in length) in HAZ's or multipass welds up to large solidification cracks, which may extend along the complete length of the welded joints.

NOTE 1 These cracks should not be confused with cold cracks, which always occur at temperatures below 200 °C.

Hot cracks are not confined to any particular alloy system and can occur in steels, stainless steels, nickel-base alloys, copper and aluminium based alloys. The reasons for the incidence of hot cracks are many and complex, but in general terms they occur when localised ductility is insufficient to support imposed strains. The lack of ductility can depend upon micro structural features and orientation (relative to the strains) and in some cases upon the presence of brittle impurities and low melting point (or liquated) films. In this respect some alloy systems are highly sensitive to the presence of impurity elements such as Sulphur, Phosphorus, Lead, etc. It is generally recognised that fully austenitic single-phase microstructures, particularly weld metals, are susceptible to hot cracking, of one form or another. Impurity levels influence the incidence of cracking in such structures.

NOTE 2 Precise mechanisms for the occurrence of hot cracking have not yet been fully established.

6 Types of test

6.1 Self-restraint tests

These tests depend upon the restraint of the weldment to provide sufficient strain to induce cracking. The tests include:

a) Those tests consisting of a highly restrained weldment where the test weld is examined directly for the presence of cracking;

b) Tests consisting of a full thickness butt weld where the test specimen is taken from the weld metal in the butt weld and subjected to additional straining to reveal pre-existing hot cracking (particularly micro fissures) and facilitate their detection and measurement. The post weld straining is applied either by tension or by bending. It is not designed to induce any new cracking.

The self-restraint tests are only suitable for the assessment of hot cracking in weld metals.

6.2 Externally loaded tests

These tests depend upon external loading on the specimen, either during the welding process or on a welded specimen which is simultaneously heated and loaded. The tests include:

a) tests where loading is imposed as the weld is deposited;

b) tests where a weld is reheated and loaded simultaneously to allow an assessment of susceptibility to be determined.

These externally loaded tests are suitable for the assessment of hot cracking in weld metals, parent materials and heat affected zones.

7 Description of tests

7.1 Self restraint tests

7.1.1 General

Details of the test procedures are given in EN ISO 17641-2.

7.1.2 T-joint weld cracking test

The test procedure is designed to assess the solidification cracking susceptibility of weld metal in a single pass restrained fillet weld. Three types of test are available, with increasing restraint being provided by increasing the thickness and/or stiffness of the plates used in the test assembly. The assessment is essentially qualitative since no direct measurement of strains is available. Assessment is based upon the length and position of cracking (if any) in the test weld.

7.1.3 Weld metal tensile test

This test is designed to assess the susceptibility to liquation and ductility dip cracking of weld metal taken from a butt weld. Applying a load to rupture a cylindrical all-weld metal specimen taken from a butt weld opens cracks initiated during the welding operation. The regions adjacent to the fracture are examined and any cracking can be detected and measured.

NOTE See EN ISO 17641-2:2004, Figures 2 and 3.

7.1.4 Longitudinal bend test

This test is designed to assess the sensitivity to solidification, liquation and ductility dip cracking in all-weld metal butt welds. Bending a test specimen taken longitudinally from a butt weld opens up cracks initiated during the welding of the butt weld. Any cracking can be detected and measured.

NOTE See EN ISO 17641-2:2004, Figures 4 and 5.

7.2 Externally loaded tests

7.2.1 General

Details of the test procedures are given in prCEN ISO/TR 17641-3.

7.2.2 Hot tensile test

Hot cracking susceptibility is determined by carrying out a tensile test while at the same time heating the specimen to simulate a thermal cycle.

A different procedure and different specimen dimensions are used to assess susceptibility to solidification cracking from those used to assess susceptibility to liquation cracking:

a) To simulate solidification cracking the specimen is heated to the melting temperature and the jaws of the equipment are held fixed so that shrinkage strains induce cracking;

b) To simulate liquation cracking specimens are heated to temperatures just below the solidus and susceptibility is based on the testing of a number of specimens to produce a hot ductility curve.

7.2.3 The Varestraint and Transvarestraint tests

The Varestraint and Transvarestraint tests are used to provide a measure of the hot cracking susceptibility by welding and loading simultaneously. In the Varestraint test the load is applied in the longitudinal direction of the weld bead under test and is capable of assessing solidification, liquation and ductility dip cracking. In the Transvarestraint test the load is applied transverse to the direction of the weld bead under test and is used only to assess susceptibility to solidification cracking. At a fixed point in the welding operation loading takes place by bending the specimen over a shaped former. On completion of the test cracking is assessed and measured visually. Susceptibility is based on an assessment of crack length versus surface strain.

7.2.4 The controlled flat tensile test

This test is carried out by the use of a single flat tensile specimen, which is strained in horizontal tensile test equipment controlled to have a linearly increasing loading rate. This controlled straining is imposed during the deposition of the weld. The strain velocity to initiate hot cracking is described as the critical strain velocity and is used as a measure of hot cracking susceptibility.

8 Summary of applications

The possible applications for the various tests are summarised in Tables 2 and 3.

Table 2 - Self-restraint hot cracking tests and applications

Type of Test	Types of Cracking	Results	Applications
T-joint weld cracking test	Solidification	Qualitative	Qualification of welding consumables Qualification test for welding consumables
Weld metal tensile tests	Solidification	Qualitative or quantitative if Microcrack Sensitivity Index $MSI_{(TT)}$ is used	Welding procedure qualification Production weld coupon test Qualification of consumables Qualification test for welding consumables
	Liquation		
	Ductility Dip		
Longitudinal bend test	Solidification	Qualitative or quantitative if $MSI_{(LBT)}$ is used	Welding procedure qualification Production weld coupon test Qualification of welding consumables Qualification test for welding consumables
	Liquation		
	Ductility Dip		

Table 3 - Hot cracking tests, types of cracking and possible applications

Type of Test	Type of Cracking	Results	Applications
Varestraint	Solidification	L_{tot} BTR	Parent material, selection and qualification
	Liquation	L_{tot}	Weld metal, selection and qualification
	Ductility Dip	L_{tot}	Welding procedures
Transvarestraint	Solidification	L_{tot}	Weld metal selection Welding procedures
Controlled flat tensile test	Solidification	V_{crit}	Material selection Multipass weldments Welding procedures Material combinations
	Liquation	V_{crit}	
	Ductility Dip	V_{crit}	
Hot tensile test	Solidification	BTR	Material selection and qualification
	Liquation	BTR	

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