# TECHNICAL REPORT

# ISO/TR 17641-3

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

## Part 3:
## Externally loaded tests



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

*Partie 3: Essais sur éprouvette soumise à une charge extérieure*



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# Foreword

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ISO/TR 17641-3 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 CEN Report..." to mean "...this Technical Report...".

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 (CEN ISO/TR 17641-3:2005) 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”.



## 1 Scope

This document outlines the test methods and procedures for carrying out externally loaded tests to assess susceptibility to hot cracking.

The following tests are described:

— Hot tensile tests

— Varestraint and Transvarestraint test

— Flat tensile test.

The above tests can provide information about the hot cracking sensitivity of parent materials, weld metals and weldments. Assessment is based upon the measurement of the "brittle temperature range" (BTR) where hot cracks occur.

This document applies primarily to austenitic stainless steels, nickel, nickel base and nickel copper alloys, weldments and welding consumables. However, the principles can be extended to other materials such as aluminium alloys and high strength steels by agreement between contracting parties.



## 2 Normative references

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



EN ISO 17641-1:2004, *Destructive tests on welds in metallic materials — Hot cracking tests for weldments – Arc welding processes — Part 1: General (ISO 17641-1:2004)*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 17641-1:2004 apply.

## 4 Symbols, designations and units

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

**Table 1 — Designation and symbols**

| Symbol | Designation | Unit |
|---|---|---|
| **Hot tensile test** | | |
| BTR | Brittle temperature range, i.e. difference between NST and DTR (see Figure 2) | °C |
| DRR | Ductility recovery rate, difference (2—3)/(1—3) × 100 (see Figure 2) | % |
| DRT | Ductility recovery temperature, i.e. temperature at 5% reduction in area measured during "on cooling" tensile test | °C |
| NDR | Nil ductility temperature range, distance (4—6 see Figure 2) | °C |
| NST | Nil strength temperature, i.e. peak temperature of the test (See Figure 2, Point 6) | °C |
| RDR | Ratio of ductility recovery, area (2—3—4)/area (1—3—5) × 100 (See Figure 2) | - |
| $R_m$ | Ultimate tensile strength | MPa |
| $Z$ | Reduction in area | % |
| $T_s$ | Solidus temperature (See Figure 2, Point 7) | °C |
| **Varestraint- and Transvarestraint test** | | |
| $L_{tot}$ | Total length of all detected hot cracks | mm |
| $l$ | Specimen length | mm |
| $R$ | Radius of the former | mm |
| $t$ | Specimen thickness | mm |
| $w$ | Specimen width | mm |
| **Flat tensile test** | | |
| $S_s$ | Specimen strain | % |
| $S_v$ | Strain rate | mm/s |
| $V_{crit}$ | Critical strain to form the first hot crack | mm/s |
| $W_s$ | Welding speed | cm/min |



## 5 Principle

Externally loaded hot cracking tests may be used to provide quantitative information on solidification, liquation and ductility dip cracking in accordance with Table 2. They are suitable for assessing the susceptibility to hot cracking of parent materials, weldments and weld metals. However it should be recognised that the exact mechanisms of the various forms of hot cracking are not fully understood. The different externally loaded tests described in this document use different criteria for the assessment of susceptibility to hot cracking. None of the tests reproduce exactly the conditions of temperature, cooling rate, restraint and externally applied strains, which occur in a wide range of fabrications where hot cracking may be considered to be a potential problem. Although work continues to address these issues, the tests in their presently developed form can only be used to rank materials, welding consumables and welding conditions. The results can then be compared with databases of relevant experience to make judgements as to potential suitability. For this reason it is not possible to state that any particular test is the most appropriate for any specific requirement. The user of the test shall decide on the basis of past experience, or on preliminary experiments, which is the most appropriate test for the required application.

Four types of hot cracking test are described and their relevance to the various forms of hot cracking, and their possible range of application, are summarised in Table 2.

All the hot cracking tests described depend on the imposition of an external load on the specimen using suitable test equipment.

This external loading can produce a measurable strain and strain rate on the specimen during the brittle temperature range (BTR) and can therefore reproduce certain aspects of the welding process. The results produced from this test are quantitative and are generally reproducible for the same test using a defined testing procedure and similar equipment.

Unfortunately, equipment and testing procedures are not standardised between different laboratories, and absolute reproducibility between laboratories is limited. Repeatability of results within a single laboratory using consistent procedures and the same equipment is generally good.

When parent materials are to be tested, the test specimen is heated either with a TIG melt run in the case of the Varestraint and flat tensile test or by resistance heating in the hot tensile test. In both cases a HAZ is formed which is subjected to straining and hence assessment of susceptibility to cracking.

When weld metal is to be tested, a weld deposit is made by the appropriate arc welding process and in the cases of the Varestraint and flat tensile test, is subjected to straining as the weld solidifies. Any cracking, which occurs, forms the basis of the assessment. For the hot tensile test the specimen is extracted from a multipass welded joint and assessment is based on measured mechanical properties using the appropriate procedure, see 6.1.1

Multipass welds can also be assessed using the Varestaint and flat tensile test, but for these tests, samples with multipass deposits have to be prepared and the weld metal is then reheated using a similar TIG melt run to that utilised in parent material tests.



**Table 2 — Hot cracking tests, types of cracking and applications**

| Type of test | Type of cracking | Results | Applications |
|---|---|---|---|
| Varestraint | Solidification | $L_{tot}$ BTR | Parent material, selection and approval. |
| | Liquation | $L_{tot}$ | Weld metal, selection and approval. |
| | Ductility Dip | $L_{tot}$ | Welding procedures |
| Transvarestraint | Solidification | $L_{tot}$ | Weld metal selection<br>Welding procedures |
| Flat tensile type<br>(PVR test) | Solidification | $V_{crit}$ | Material selection, |
| | Liquation | $V_{crit}$ | Multipass weldments |
| | Ductility Dip | $V_{crit}$ | Welding procedures<br>Material combinations |
| Hot tensile test (Gleeble ™) | Solidification | BTR | Material selection and approval |
| | Liquation | BTR | |

Although it is possible for more than one form of hot cracking to be present in a given test piece it should be noted that the formation of one type of cracking e.g. solidification, may relieve the test strain on the specimen to such an extent that other forms of cracking do not occur. Therefore the lack of a particular form of cracking in the testpiece, does not mean that there is no risk of that type of cracking occurring in practice.

The Transvarestraint test was primarily designed to assess weld metal solidification cracking by applying strains transverse to the length of the weld. It is possible that other types of hot cracking form and if these do occur, they should be noted on the test report.

# 6 Description of the tests

## 6.1 Hot tensile test

### 6.1.1 General

The hot tensile test determines the hot cracking susceptibility of a material in a simulated welding thermal cycle using a cylindrical shaped tensile specimen. The specimen can be abruptly broken at any convenient moment in the welding thermal cycle. For the study of hot cracking where it is necessary to simulate fusion welding thermal heating, a specimen shall be heated to its melting temperature. A number of cylindrical tensile test specimens are used, which can be loaded to failure at a predefined point (Procedure A).

To simulate the HAZ thermal history and liquation cracking, the specimen is heated only as far as the nil strength temperature (NST) rather than the melting point. This procedure is the same for both liquation cracking in the HAZ of parent materials and the interrun HAZ's of multipass welds (Procedure B). The test procedures are primarily used in weld metal hot cracking studies. The tests are characterised by good reproducibility.

### 6.1.2 Specimen size

Procedure A — to simulate solidification cracking and heating to the melting point, a specimen of length 130 mm and diameter 10 mm should be used.

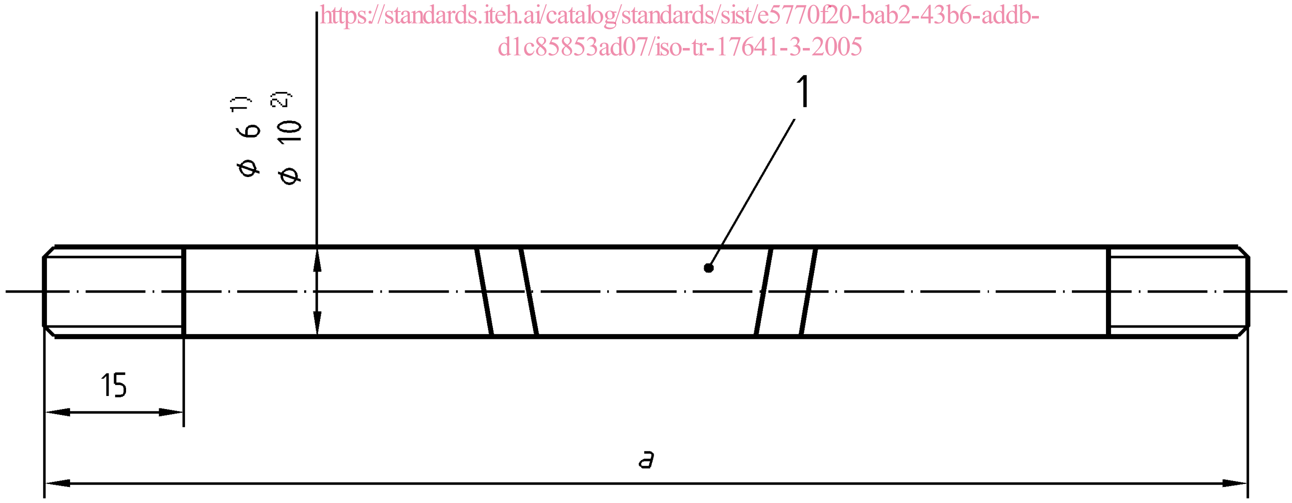
Procedure B — to simulate HAZ liquation cracking and to determine the NST, a specimen of length 110 mm and diameter 6 mm should be used.



The specimen dimension together with the location of the weld joint are shown in Figure 1.



Dimensions in millimetres




**Key**

1 Weld metal
a = 130 for solidification cracking
110 for liquation cracking

1) for liquation cracking
2) for solidification cracking

**Figure 1 — Specimen dimensions for the hot tensile test**

### 6.1.3 Protective atmosphere

The test specimens shall be heated in a chamber, which is first evacuated and then back-filled with Argon to prevent excessive oxidation at high temperature. Any suitable means of back filling can be used, provided the oxygen content of the atmosphere at the start of the test does not exceed 0,1 %.

### 6.1.4 Test procedure

#### 6.1.4.1 General

Temperature measurement of the specimen should be carried out by percussion welding a 0,2/0,25mm diameter Pt-PtRh thermocouple fixed to middle of the specimen length and perpendicular to the diameter of the specimen.

#### 6.1.4.2 Procedure A — Solidification cracking studies

The 10 mm diameter specimen is mounted in water cooled copper jaws and then heated to the melting point using controlled resistance heating. The central portion of the specimen is prevented from collapse, as it nears the melting point, by a close-fitting quartz tube. During solidification and on further cooling the jaws are held fixed so that the shrinkage strains/restraint can induce cracking.

In subsequent tests, controlled compression can be superimposed after the heating cycle to establish the strain necessary to avoid cracking.

#### 6.1.4.3 Procedure B — Liquation cracking studies



To determine the peak nil strength temperature (NST), the 6 mm diameter specimen should be heated to between 50 °C and 100 °C below the solidus temperature at heating rate of approximately 50 °C/s (and up to 250 °C/s for some alloys). At this stage the heating rate should be reduced to about 2 °C/s until the specimen breaks under a constant load of approximately 100 N. The hot ductility can be determined using on-heating and on-cooling tests. For the on-cooling tests the specimen shall be heated to the NST and then cooled to the test temperature in order to conduct the tensile test.



For on-heating tests the specimen need only be heated to the test temperature and then subjected to the tensile loading at a strain rate of 50 mm/s. Heating and cooling rates should correspond to the weld metal thermal cycle being simulated.

During heating, free expansion of the specimen should be permitted. However, if data is available from a real situation, using the equipment programmes can simulate then welding strains. During cooling, free shrinkage of the specimen should be permitted or, alternatively, a controlled compression can be applied until the ductility recovery temperature (DRT) is reached.

This compensates for the specimen contraction in the axial direction and can be used to provide a quantitative measurement of strains necessary to prevent cracking in the specimen. A minimum of 12 specimens is usually required to establish a reliable hot ductility curve.

### 6.1.5 Test results

After testing, the reduction in area ($Z$) shall be calculated from the fractured cross sectional area as a fraction of the original cross section of the test specimen. The ultimate tensile strength ($R_m$) can be obtained by dividing the maximum force by the initial cross-sectional area of the specimen. This ultimate tensile strength and the reduction of area should be plotted for both on-heating and on-cooling tests as a function of test temperature. Typical plots are shown in Figure 2.