SLOVENSKI STANDARD
SIST CWA 15627:2008
01-marec-2008

Preskusna metoda za kovinske materiale z uporabo majhnega bata (Small Punch Test)

Small Punch Test Method for Metallic Materials

Ta slovenski standard je istoveten z: **CWA 15627:2007**

ICS:
77.040.10

SIST CWA 15627:2008 **en**

CEN

WORKSHOP

AGREEMENT

CWA 15627

December 2007

ICS 77.040.10

Supersedes CWA 15627:2006

English version

Small Punch Test Method for Metallic Materials

This CEN Workshop Agreement has been drafted and approved by a Workshop of representatives of interested parties, the constitution of which is indicated in the foreword of this Workshop Agreement.

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Ref. No.:CWA 15627:2007 D/E/F

CONTENTS

Part B: A Code of Practice for Small Punch Testing for Tensile and Fracture Behaviour

Foreword

This CEN Workshop 21 on “Small Punch Test Method for Metallic Materials” has been established and a Business Plan approved by a Workshop of representatives of interested parties on 2004-09-24 [1], the constitution of which was supported by CEN following the public call for participation made on 2004-09-08.

Following a decision from the Workshop, it has been decided to re-publish CWA 15627:2006 in order to correct a typing error in a formula. This version corrects and supersedes the CWA published in December 2006.

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The final review/endorsement round for this CWA was successfully closed on (2007-10-29).

This CWA has been developed with the aim of providing guidance in the selection of the experimental conditions in a special type of mechanical test, namely the Small Punch (SP) test, suitable to obtain robust, reproducible and accurate results. In addition to recommending in the main body of this document the experimental procedures (“code of practice”), in two separate annexes guidance is given in the interpretation of the SP test results (namely the question of the comparability with / derivation of fundamental material strength data, i.e. those from the standard tests), and guidance in the use of SP tests to address relevant technological issues (e.g. specimen sampling from components, characterization of heat affected zones in welds, SP test applicability for non isotropic materials ...).

Actually two main versions of this SP test were developed historically, covering the two distinct scopes of measuring mechanical properties of materials in the high temperature (time dependent, creep viscous) and low temperature (time independent) domains. Not only the experimental set up and test procedures have to be different in order to match the distinct aims and conditions of time-dependent and time-independent SP testing, but also the technological & market scenario (the demand of SP tests by industry) is often different too; consequently, depending on their business position and strategy, some labs had been developing (or newcomers may be willing to develop) the high temperature version, while others developed (or would like to develop) the low temperature version only.

Therefore, in view of the considerations above, the group of developers of this document felt convenient to provide a document made of two main and fully self-consistent parts, having the maximum flexibility of current use and of future development routes (modifications, standardizations):
Part A is for time dependent SP testing,
Part B is for time independent SP testing,
each part is equipped with its own Annexes, A1 and A2 for Part A and B1 and B2 for Part B,
it is noted only that A2 and B2 are identical.

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Comments or suggestions from the users of the CEN Workshop Agreement are welcome and should be addressed to the CEN Management Centre.

Part A: A Code of Practice for Small Punch Creep Testing

0. INTRODUCTION

The life assessment and potential for possible failure of in service components is a critical issue in the safety and reliability analysis of industrial plants. In the case of plant operating at elevated temperature for long times, any of several degradation processes may potentially impair the mechanical properties, in particular the creep resistance, of their structural components. For most of the plant operating currently, the design life at the time of construction was usually based on relatively simplistic codes endorsed by practical experience, and finally corrected by an appropriate safety factor. Indeed, in light of the major advances in metallurgical knowledge and currently available analytical methodologies, today it would be possible to reduce the safety factor and to thus extend design lives. In addition, the new policies for environmental protection and the safety regulations for industrial plants make it more practical and economically convenient to extend the lifetime of existing component beyond their original design life rather than to build new plants. However, major investment to modernise and make existing plants more efficient is only profitable if the plant under consideration has sufficient residual life. Hence, reducing the uncertainty in the estimation and monitoring of remaining life of plant components is of fundamental importance to industry.

The component integrity can be rarely evaluated with the traditional and well-standardised mechanical test techniques, such as the uniaxial creep test, because there is insufficient material to sample non-invasively from the component. Hence, the need for evaluating the residual mechanical properties of structural components by direct testing methods has led to innovative techniques based on miniaturised specimens. Among these, a technique called the Small Punch Creep (SPC) test has emerged as a promising candidate as it can be considered as effectively a non-destructive technique because of the very limited amount of material to be sampled. It is an efficient and cost-effective technique and has the potential to enable measurement of the realistic material properties for the specific component, identifying the present state of damage and focusing on the more critical (more stressed, more damaged) locations in the component. Before the promise of the technique can be turned into reality, a standardized and acceptable test methodology must be made available which is the fundamental purpose of this Code of Practice.

This document guides the user through several steps necessary to carry out a SP Creep test. The available methods for analysing the test records and, when needed and feasible, to infer basic, fundamental material characteristics (i.e. test method independent, specimen size independent) are described in Annex A1. Moreover in the Annex A2 informative guidance is given on industrial and technological issue: e.g. sampling guidance such as for example from components, from coated elements in gas turbines, from weldments.

1. SCOPE

This Code of Practice gives guidance on the procedure to be followed when carrying out Small Punch Creep tests. The objectives of such tests are to evaluate the creep behaviour of materials exposed in operating plant components in order to provide data needed for plant life and integrity assessment. The Code of Practice primarily addresses metallic materials tested under creep loading but can also be used for other materials. Determination of tensile test data at elevated temperature can also be realised using the proposed methodology. But the methodology applied in Part B of this document should be applied.

The scope of the Code of Practice covers the following:

Test Piece

Test pieces are discs of specified dimensions procured from components or any other source. They may be homogeneous or contain manufacturing features such as for example joints, weldments, defects or coatings

Load

The load may be applied to the disc from a pneumatic, hydraulic or any other mechanical source. The Code of Practice particularly addresses the usual situation where the load is maintained constant throughout the test, but the general principles apply also to tests where the load is cycled, with dwell periods.

Temperature

The test temperature will usually be within the creep range for the materials under test. The Code of Practice specifically addresses the usual situation where the temperature is maintained constant throughout the test, but the general principles also apply to thermal cycling with or without dwell periods.

Environment

The test pieces will usually be tested in an inert gas environment. However, the general principles should also apply when other environments are used. Although special precautions will be necessary where hazardous or corrosive environments are used, these are not detailed in this document.

2. DEFINITIONS

For the purpose of this Code of Practice, the symbols and designations are as given in Table 1 and the following definitions apply.

2.1 Small Punch test

A mechanical test carried out on a small disc shaped test piece by means of the application of a mechanical load applied to one surface of the test piece by means of a shaped punch in order to investigate its response to the load.

2.1.1 Small Punch Bulge test

As 2.1 above, but under the condition that the perimeter of the disc is clamped and does not displace during the test.

2.1.2 Small Punch Drawing test

As 2.1 above but under the condition that the perimeter of the disc is not fully clamped and may displace during the test.

2.2 Small Punch Creep Test

Small Punch Test carried out under creep conditions

2.2.1 Test Piece

The disc under investigation, independent of its material of composition, its structure and its manufacturing route.

2.2.2 Test Piece Environment

The environment which is in contact with all surfaces of the test-piece.

2.3 Small Punch Creep Test Stress

The calculated stress induced in the test piece by the load, considered equivalent to the initial stress in a uniaxial test piece or component under creep conditions.

Table 1 - Symbols and Designations

Symbol	Unit	Designation
h_0	mm	SP disc initial thickness
r	mm	Radius of punch indenter
d	mm	Diameter of disc
D,R	mm	Diameter, radius of receiving aperture
L	mm	Length of receiving die edge chamfer
u_1 ,u_2	mm	Punch Displacement, Disc Deflection respectively
V	m/s	Punch velocity
F	N	Punch load
σ	Pa	SP disc initial stress (calculated)
k_{SP}	-	SP creep test correlation factor
t	s	Test time
T	K	Test Temperature

3. APPARATUS

The apparatus should comprise some or all of the following:

3.1 Test Rig

Fig. 1 illustrates schematically a cross-sectional view of the specimen holder with a spherical punch and the test specimen. It is recommended that, prior to the test, the holder is forced to clamp the specimen rigidly to limit specimen deformation in the region at the hole of the lower fixture. It is accepted that the test can be carried out without the disc being fully clamped but rather guided, known as clamp without load. For such a case this aspect must be recorded in the test report as this is known to influence the stress to which the disc is subjected. The receiving aperture of radius R is recommended to be 2mm with a 45^0 chamfer at R + 0.2mm. The materials of construction of the upper and lower die should be the same and of a similar coefficient of thermal expansion to the disc under test so as to minimise thermal stresses. The surface of the upper part of specimen holder in contact with the test specimen shall be plane and parallel to the surface of the lower part of specimen holder. Both surfaces shall be clean and free from oxide build-up, corrosion and dirt. The working surfaces of the upper and lower part of the specimen holder shall have a hardness of 55 HRC or higher. The test rig shall have a spherical (hemispherical)-ended punch capable of forcing the central portion of the test specimen through the aperture in the receiving die until the end point of the test occurs. Alternatively a spherical ball indenter may be used but is not recommended due to the difficulty to avoid ovality, the possibility of its' lateral displacement and the risk of it embedding within the disc at the end of the test. The hemispherical portion of the punch or alternatively the sphere shall have hardness not less than 55 HRC to be sufficiently rigid so as not to be deformed during the test. The punch radius r is recommended to be between 1.0 and 1.25mm.

3.2 Loading System

The method of application of the load shall be such that the load can be controlled to ±1% agreeing with the latest recommendations for creep testing provided by the European Creep Collaborative Committee (ECCC) and the draft EN/ISO standard for uniaxial creep testing of metallic materials. The loading system should be calibrated for accuracy using a proving ring or similar certified device and the results recorded at least once per annum.

3.3 Strain Measurement System

Extensometry, strain gauging or other methods of determining the deformation of the test-piece in a continuous fashion may be used providing that they are suitably calibrated and applied in accordance with good testing practice and the manufacturer's instructions. The accuracy and frequency of disc deflection measurements will be determined by the nature of the actual test being done. Alternatively, or additionally, the displacement of the punch should be continuously recorded. The difference between punch displacement and disc deflection represents eventual thinning of the disc and should be recorded if possible.
Furthermore, a discontinuous method may be employed to take dimensional measurements. The technique is analogous to the taking of interrupted strain measurements during a uniaxial creep test and should conform to the appropriate standard. The method also permits the dimensions at a large number of locations within the disc to be monitored during the test but has serious drawbacks associated with re-insertion of the disc specimen after measurements.

3.4 Heating System

The heating system should provide a uniform temperature distribution throughout the test section of the disc. In the case of a clamped perimeter in the Small Punch Bulge test, the section beneath the clamp is not considered as part of the test section.
A temperature measuring system is to be supplied comprising thermometers, usually thermocouples, appropriately located to determine that the full test section remains within the temperature limits prescribed for the test. The thermocouples should be of a type and composition suitable for the test temperature regime selected for the test and calibrated in accordance with the appropriate ISO or EN standard.
The temperature control system should be capable of maintaining the temperature constant to within ± 0.25% of the set temperature in degrees absolute, K, by automatic means throughout the test. See Table 2 for conversion to degrees C and comparison with the draft EN/ISO standard for uniaxial creep testing of metallic materials.

3.5 Test Environment

Due to the small dimensions of the Small Punch Creep test-pieces, it is recommended that the tests are carried out in an inert environment to prevent oxidation or corrosion of the exposed surfaces of the test-piece. For studies where the effect of the environment on creep behaviour is of specific interest, other environments may be employed but this purpose must be clearly stated in the test report and the publication of the test results. For all environments, including inert environments, the composition should be known and, if necessary, strictly controlled within specified limits.

3.6 Additional Measurements

Other test parameters may be monitored such as crack initiation or growth either by continuous (potential drop, acoustic emission) or by discontinuous methods. These additional measurements may not be allowed to affect the results of the Small Punch Creep test itself. Any additional measurement made should be reported with the test results.

3.7 Data recording

Equipment should be provided which will record the test parameters automatically with a resolution which matches that of the measuring instruments and should be accurate to within ±1% of full scale deflection at least and preferably within, ±1% of the measured signal, when all sources of error are taken into account.

4. TEST PIECES

4.1 Design

A single test piece design is recommended in this Code, which is a disc of diameter, d, 8mm and initial thickness, h_0, 0.5mm. Exceptions to these dimensions can be accepted provided that they are fully reported with the test results as follows:

i) a larger diameter is allowed for the case of a Small Punch Bulge Test where the disc is clamped with load around its periphery. The clamped area should be greater than one third of the total area.
ii) a different disc thickness is allowed if there is a good justification made for micro-structural reasons such as grain size, coating thickness, inclusion of a weldment etc.

4.2 Manufacture and metrology

The test piece is to be procured from standard test material, e.g. bar or sheet or from engineering components prior to or during operation. Methods for extracting material from components are detailed in Annex A2. In order to minimise work hardening in the surface of the test piece, the disc should be machined to a thickness of approximately 0.55mm and then ground to at least 200 grit on both sides (one side for coated specimens) to achieve the final dimension of 0.5mm with a tolerance of no more than ±0.5%. With the exception of the case mentioned in 4.1 i) above for a specimen clamped with load, the disc diameter should be 8mm ±1%. The thickness of the test piece should be measured at four positions around the perimeter at 90° intervals and at the central position. The diameter should be measured in two positions at 90°

4.3 Identification and documentation

Test-pieces should be permanently marked on the curved edge with a unique identifier. The position of the identifier should also enable the position of the four thickness measurements to be traced.
A written record of each test piece should be kept, listing:

Identification
Material composition and cast
Material condition and original location
Test piece manufacturing route
Test piece original dimensions

This information should be transferred to the test documentation to form a complete test record.

5. TEST PROCEDURE

5.1 Test piece installation

a) Insert the test piece and clamp it centrally into its position
b) If preparing for an SP Drawing test, clamp the test-piece without load.
c) Locate the extensometer against the test-piece at its centre opposite to the punch tip
d) Close the system and evacuate and flush twice with high purity argon or other appropriate inert gas. In some cases an active gas may be used if required for the purpose of the test.

5.2 Determination of test load

The applied load in any test has to be determined from geometrical factors and material properties in order that creep failure in the Small Punch test will occur at the same time as that in a conventional uniaxial creep test at the same temperature. For the case where there is no prior information on expected behaviour, the ratio of SP test load (F) to the uniaxial creep stress (σ) should be given by:

$$F/\sigma = 3.33 k_{SP} R^{-0.2} r^{1.2} h_0$$

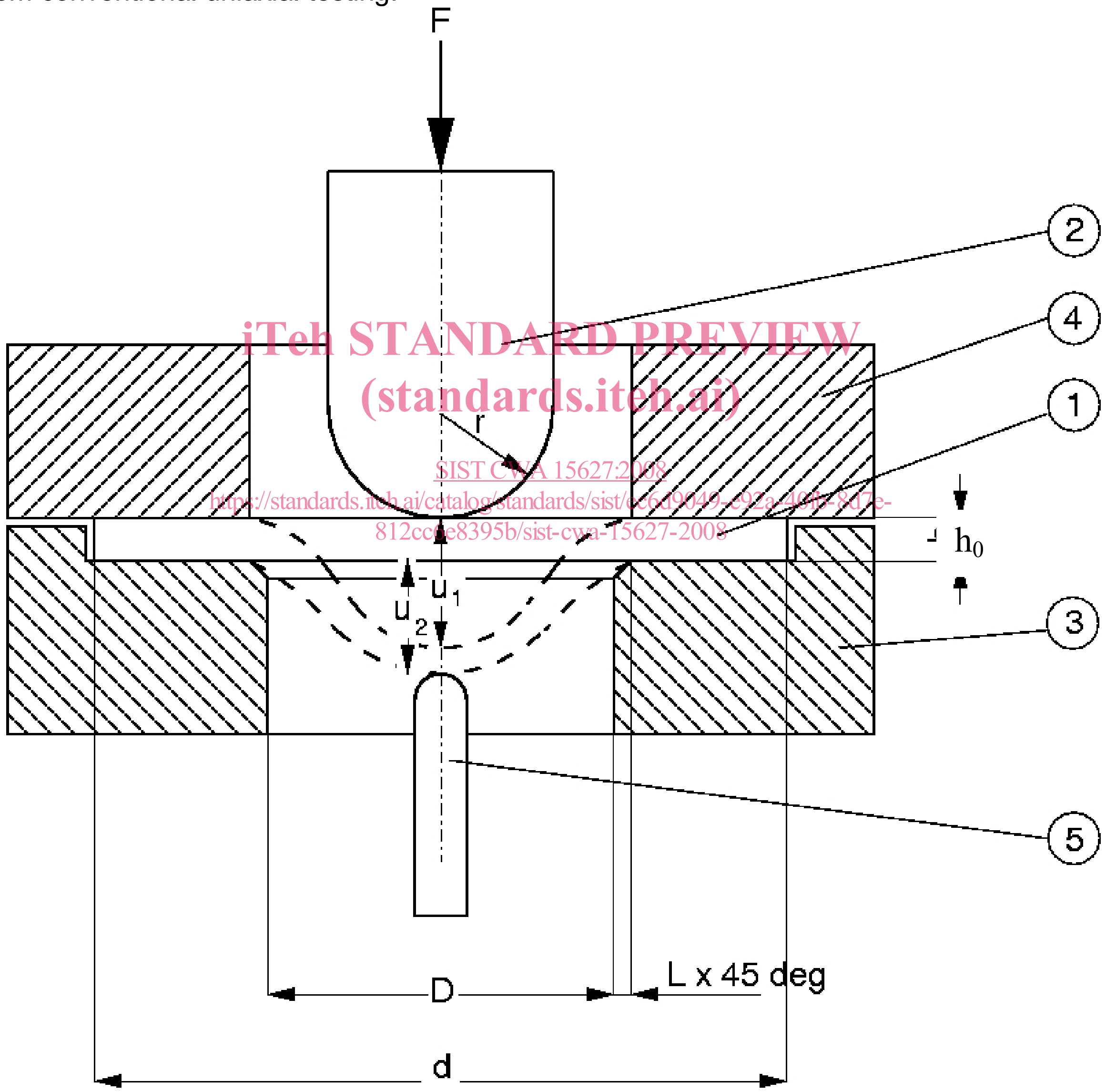
where

r is the radius of the punch indenter,

h_0 is the test-piece thickness,

R is the radius of the receiving hole.

This equation is derived from stretching membrane theory (Annex A1) and applies for an unclamped test providing the disc deflection exceeds 0.8 mm. For the case of the disc clamped with load it is estimated that this ratio should be reduced by approximately 20%. The SP creep test correlation factor, k_{SP}, has first to be determined empirically for the particular material under test. Where k_{SP} is not known, the first tests should be set up assuming k_{SP}=1 and a series of a minimum of 5 tests at one particular temperature carried out in order to evaluate k_{SP} through comparison with the stress rupture behaviour defined from conventional uniaxial testing.



Key

1. SP disc test-piece
2. Hemispherical ended punch
3. Lower die
4. Upper die
5. Dilatometer push rod

Figure 1 - Geometry of the SP Creep test installation