SIST

# SLOVENSKI STANDARD
# SIST EN 3873:2011

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**Aeronavtika - Preskusne metode za kovinske materiale - Ugotavljanje stopnje rasti razpok, ki nastanejo zaradi utrujenosti, z uporabo preskusnih kosov z razpokami na robovih (CC)**

Aerospace series - Test methods for metallic materials - Determination of fatigue crack growth rates using Corner-Cracked (CC) test pieces

Luft- und Raumfahrt - Prüfverfahren für metallische Werkstoffe - Ermittlung der Rißfortschritts- Geschwindigkeit an Cornercrackproben (Eckanris)



Série aérospatiale - Méthode d'essais applicables aux matériaux métalliques - Détermination de la vitesse de propagation de fissure en fatigue à l'aide d'éprouvettes avec fissure en coin



**Ta slovenski standard je istoveten z:** **EN 3873:2010**

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**ICS:**

49.025.05 Železove zlitine na splošno Ferrous alloys in general

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# Aerospace series - Test methods for metallic materials - Determination of fatigue crack growth rates using Corner-Cracked (CC) test pieces

Série aérospatiale - Méthodes d'essais applicables aux matériaux métalliques - Détermination de la vitesse de propagation de fissure en fatigue à l'aide d'éprouvettes avec fissure en coin

Luft- und Raumfahrt - Prüfverfahren für metallische Werkstoffe - Ermittlung der Rißfortschritts- Geschwindigkeit an Cornercrackproben (Eckanris)

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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EUROPÄISCHES KOMITEE FÜR NORMUNG

**Management Centre: Avenue Marnix 17, B-1000 Brussels**



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# Foreword

This document (EN 3873:2010) has been prepared by the Aerospace and Defence Industries Association of Europe - Standardization (ASD-STAN).

After enquiries and votes carried out in accordance with the rules of this Association, this Standard has received the approval of the National Associations and the Official Services of the member countries of ASD, prior to its presentation to CEN.

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of an identical text or by endorsement, at the latest by May 2011, and conflicting national standards shall be withdrawn at the latest by May 2011.

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## Introduction

This standard and its parts belong to the general organization of the ASD collection of metallic material standards for aerospace applications

## 1 Scope

This standard specifies the requirements for determining fatigue crack growth rates using the corner-crack (CC) test piece. Crack development is measured using a potential-drop system, and the calculated crack depths can be corrected via marker bands created on the fracture surface during the test. Results are expressed in terms of the crack-tip stress-intensity range ($\Delta K$), with crack depths and test stress level noted.

## 2 Normative references

The following referenced documents are 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 2002-002, *Aerospace series — Metallic materials — Test methods — Part 002: Tensile testing at elevated temperature*

EN ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system (ISO 7500-1:2004)*

EN ISO 3785, *Metallic materials — Designation of test specimen axes in relation to product texture (ISO 3785:2006)*



ASTM E 647-2008, *Standard test method for measurement of fatigue crack growth rates* [1)]



ASTM E 1012-2005, *Verification of test frame and specimen alignment under tensile and compressive axial force application* [1)]



## 3 Symbols and abbreviations

$a$ — Crack depth. The crack depth $a$ is the distance from the extrapolated original corner containing the notch to the centre of the crack front (45° position). For the calculation of stress-intensity factor, the crack length must be given in metres

$a_e$ — Final crack depth (in millimetres)

$a_i$ — Initial crack depth (in millimetres)

$a_m$ — Measured crack depth (optical, post-test fracture surface micrography or with SEM)

$a_v$ — Calculated (Potential) crack depth
is the average crack depth due to the averaging nature of the potential measurement method. Calculation involving average lengths measured at several positions along the crack front are best for correlation with the potential measurements (in millimetres)

$\Delta a$ — Crack growth increment (in millimetres)

da/dN — Fatigue crack growth rate (FCGR) (in metres per cycle)

$W$ — Test piece width (in millimetres)

1) Published by: American Society for Testing and Materials (ASTM), http://www.astm.org/.

$a/W$ Normalized crack depth (in millimetres/millimetres)

$f$ Frequency (in Hertz)

$E$ Young's modulus (in gigapascals)

$K$ Stress-intensity factor (general)
The stress-intensity factor $K$ is a load parameter which characterises the stress field at the crack tip. It is a function of load, crack depth and test piece geometry (in MPa $\sqrt{m}$)

$K_{max.}$ Maximum value of $K$ during a loading cycle, corresponding to the maximum tensile force applied (in MPa $\sqrt{m}$)

$K_{min.}$ Minimum value of $K$ during a loading cycle (in MPa $\sqrt{m}$)

$\Delta K$ Range of $K$ during a loading cycle = $K_{max.} - K_{min.} = (1 - R)^*K_{max.}$ (in MPa $\sqrt{m}$)

$\Delta K_{eff}$ Effective range of $K$, due to crack closure-induced reduction applied $\Delta K$ (in MPa $\sqrt{m}$)

$\Delta K_{th}$ Fatigue crack growth threshold
The asymptotic value of $\Delta K$ for which da/dN approaches zero. For most materials the operational threshold is defined as the $\Delta K$ corresponding to $10^{-7}$ m/cycle. When reporting $\Delta K_{th}$, the corresponding lowest decade of near threshold data used in its determination must be given

$C$ Normalized K-gradient $C = (1/K \times dK/da)$. For load-shedding to attain a desired initial $\Delta K$, $C$ defines the fractional rate of change of $K$ with increasing crack depth $a$.
$C = 1/K \times dK/da = 1/K_{max.} \times dK_{max.}/da = 1/K_{min.} \times dK_{min.}/da = 1/\Delta K \times d\Delta K/da$, (in $mm^{-1}$)



$N$ Number of loading cycles
Stress cycle (fatigue cycle, load cycle) is the smallest segment of the loading waveform spectrum which is repeated periodically

$N'$ Number of stress cycles between two marker cycles

$N_m$ Number of stress cycles in a marker cycle

$\Delta N$ Stress cycle difference

$r$ Notch radius (expressed in millimetres)

$F_m$ Mean force (expressed in kilonewtons)

$F_{max.}$ Maximum tensile force applied to the test piece during a cycle (expressed in kilonewtons)

$F_{min.}$ Minimum tensile force (in kilonewtons)

$\Delta F$ Force range (in kilonewtons), $\Delta F = F_{max.} - F_{min.}$

$q$ Resolution of crack depth measuring system (expressed in millimetres)

$R$ Force ratio ($= F_{min.}/F_{max.} = K_{min.}/K_{max.}$)

$R^*_m$ Ratio $F_{min.}/F_{max.}$ during a marker cycle

$R_p$ 0,2 % offset yield strength (Proof Stress $R_{p0,2}$) at test temperature (expressed in megapascals)

$R_m$ Tensile strength at test temperature (expressed in megapascals)

$\sigma_f$ Flow stress – here defined as the arithmetic mean of $R_p$ and $R_m$ (expressed in megapascals)

$Z$ Axial distance from crack plane to each wire used for potential measurement (expressed in millimetres) – ($2Z$ = wire separation distance)

## 4 General

**4.1** The corner-crack (CC) test piece is useful in determining da/dN for components where the cracks usually appear at a corner, such as in holes in turbine disks. The determination involves the use of an axially-loaded test piece of square or rectangular cross-section. It may be loaded in tension and compression for positive and negative stress ratio testing if suitable end designs permit backlash-free loading.

A carefully defined and produced notch or a small arc strike enables cracking to be initiated at the centre of the reduced section. A fatigue crack is induced at the root of the notch by cyclic loading, and its growth is monitored by a suitable method, e.g. potential drop techniques. As the crack grows, the force range applied to the test piece is maintained or reduced in a controlled manner until the cracks are of sufficient depth for the influence of the notch and the crack initiation method to be negligible, and the $\Delta K$ has reached the lowest level of interest. The test is then carried out. The force range is maintained constant and the crack depth recorded as a function of elapsed cycles. These data are then subjected to numerical analysis, enabling da/dN to be determined as a function of $\Delta K$.

**4.2** The majority of metallic materials can be tested using the method described here, provided that the force applied is such as to ensure that the plastic zone in front of the crack tip is small in relation to the remaining cross section (linear-elastic criterion).



**4.3** The test piece used here is a corner-crack (CC) test piece. See Figure C.1.



**4.4** In the standard crack-growth test the load amplitude is assumed to be constant throughout the test, after the required $\Delta K$ level and $R$-ratio is reached. Another load range can be added if certain transient effects are to be investigated.

**4.5** The range of the stress-intensity factor $\Delta K$ is:

$$\Delta K = K_{max.} - K_{min.} \tag{1}$$

where the ratio $R$

$$R = \frac{K_{max.}}{K_{min.}} \tag{2}$$

applies.

From Equations (1) and (2) it follows that, for $R > 0$, $\Delta K = (1 - R)\, K_{max.}$ (3)

**4.6** The reference point for measuring the crack depth with CC test pieces is the original corner of the test piece, determined by the projections of the sides of the test piece on the fracture surface adjacent to the notch. Possible rounding of the corner during test piece manufacture will result in this reference point being no longer on the fracture surface. This rounding must be determined to obtain a “Zero-point offset” between the reference point and the rounded corner where the measurement wire is welded, which is used in the calibration of the potential-drop measurements.

**4.7** The purpose of the crack propagation measurements is to allocate the relevant load cycles $N$ to the crack depth a. The measurements (a-N points, see Figure C.2) are normally evaluated in the form of a da/dN versus $\Delta K$ curve (see Figure C.3). It is not always the case that the crack propagation can be described by the range of stress-intensity factor $\Delta K$. If it cannot be so described, other laws can be applied, e.g. crack growth rate as a function of $K_{max}$.

**4.8** The crack growth behaviour depends on a number of parameters. The framework within which the test is to be carried out needs to be precisely defined in order to avoid undesired effects on the results.

The most important factors affecting the results are:

a) temperature and environment;

b) load spectrum.

The test parameters $R$, dwell time and loading frequency must be defined and recorded before testing commences. The results can also be affected by the loading history, including interruption times, e.g. stop and restart of cycling to check surface crack length or other parameters, work stoppage at weekends, etc. These should be recorded.

c) Residual stresses

Residual stresses are usually ignored, as they are difficult to determine, and a duplication of the residual stresses in a component is very difficult to obtain in a test piece. Their presence in a component will affect the life of the component, and should be regarded in the use of the crack growth data. The presence of unexpected residual stresses in the test piece may be witnessed in an asymmetry of the crack front.



**4.9** Applicability of results

The crack-growth measurements are generally used for:



a) investigating the influence of fatigue-crack growth on the predicted life of a component, or for evaluating the crack-growth resistance of a material or heat-treat condition;

b) defining the requirements of NDT testing; and

c) macroscopic quantitative determination of various factors (e.g. load, microstructure, manufacture, etc.).

# 5 Resources

## 5.1 Test machine

### 5.1.1 General

Tests shall be performed with a feed-back load-controlled servohydraulic or electromechanical test system designed for smooth loading from first load cycle without exceeding the desired $F_{max}$. The system should be capable of halting the cycling at desired intervals of cycles or crack depth, at a desired potential level, or at will, to enable measurements of the optical crack depth, potential or thermal potential, without stopping the test or causing overloads during the following restart.

### 5.1.2 Load control

The apparatus must satisfy the following requirements in accordance with EN ISO 7500-1:

a) accuracy of electronic force measurement: ± 0,5 % and ± 0,25 % of nominal range respectively;

b) accuracy of control throughout testing: better than 0,5 % of specified value of $\Delta F$;

c) recording instrument voltage requirements (upper and lower stress range, cycles): digital recorder is recommended;

d) recording accuracy throughout testing: better than 0,25 %.

#### 5.1.3 Load alignment

Good alignment in the load train is essential for ensuring loading symmetry. An alignment test should be carried out. The loading train should be rigid, to avoid loading eccentricity as the crack grows, which would influence the applied stress-intensity factor at the crack tip. Alignment should be carried out in accordance with ASTM E 1012.

### 5.2 Calibration

All instruments shall be calibrated at least once a year, as well as after every incident that may have affected the calibration accuracy. Multiplication factors (e.g. ×10 or ×100) shall not be used when counting the cycles, unless the factor is less than $10^{x-2}$, where $10^{-x}$ mm/cycle is to be measured.

Thermocouples should be calibrated every six months in accordance with EN ISO 3785.

### 5.3 Temperature measurement and control



Temperature of the test piece shall be measured by a calibrated Platinum/ Rh (Type R) or Chromel-Alumel (Type K) thermocouple in adequate thermal contact with the test piece, at the centreline of one face adjacent to the notch, 2 mm to 4 mm above or below the crack plane. Shielding of the junction from radiation is not necessary if the difference in indicated temperature from an unshielded bead and a bead inserted in a hole in the test piece has been shown to be less than one-half the permitted variation shown below.



Throughout the test, the temperature shall not deviate from the specified values by more than the following:

For elevated temperature tests up to (1 000 ± 3) °C: (1 000 ± 4) °C to (1 100 ± 4) °C.

Temperatures shall be recorded and monitored, irrespective of the accuracy of temperature control, by each change of 1 °C.

The recording accuracy shall be better than 0,25 % of the specified value.

Room temperature variations; i.e. at night, over weekends, should be known and limited to ± 5 °C.

For tests at elevated temperatures, a three-zone furnace featuring electronic PID control shall be used. The grips must also be heated.

### 5.4 Gripping of test pieces

To compensate for the weight of the grips and fixtures, the load cell must be adjusted to ensure that the test piece is not under stress at zero indicated force.

## 6 Test pieces

### 6.1 Corner-crack (CC) test piece

The corner-crack (CC) test piece is illustrated in Figure C.1. CC test pieces may be used with positive or negative $R$-ratio loading, assuming the gripping system can transmit loads without backlash.

### 6.2 Stress-intensity − Factor calculation

The stress-intensity factor for the CC test piece is calculated as follows (Annex B describes this in more detail):

First, the geometry factor for the 45° position is calculated:

$$Y_{45°} = 0{,}574 + 1{,}199\,(1 - a/W) - 1{,}324\,(1 - a/W)^2 + 0{,}4845\,(1 - a/W)^3 \quad (4)$$

Then, for crack depths $a \leq 0{,}2\ W$:

$$Y = 1{,}143\,(1 + 0{,}6\ a/W)\,(1 + 0{,}7\ a/W)^2\,(2/\pi)\,Y_{45°} \quad (5)$$

and for crack depths $a > 0{,}2\ W$:

$$Y = [0{,}1\,(a/W)^2 + 0{,}29\,(a/W) + 1{,}081] \times [0{,}75\,(a/W)^2 - 0{,}185\,(a/W) + 1{,}019] \times [(\,0{,}9\,(a/W)^2 - 0{,}21\,(a/W) + 1{,}02\,)]\ 2/\pi \times Y_{45°} \quad (6)$$

and

$$K = \frac{F \times Y}{W^2} \times \sqrt{\frac{\pi \times a}{10}} \quad (7)$$

where

$a$ is the crack depth (expressed in centimetres);

$W$ is the test piece width (expressed in centimetres);

$F$ is the force (expressed in kilonewtons);

$K$ is the stress-intensity (expressed in MPa√m).



A check for this calculation may be made with the following input and results:

$a$ 1 mm (0,1 cm);

$W$ 0,8 cm;

$F$ 32 kN.

here

$Y$ 0,691;

$K$ 19,365.

### 6.3 Test piece size requirements

For the results to be valid, the test pieces are to be subjected to a stress within the elasticity range of the material for all values of the applied load.