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Corrosion of metals and alloys — Stress corrosion testing —

Part 9:
Preparation and use of pre-cracked specimens for tests under rising load or rising displacement

Corrosion des métaux et alliages — Essais de corrosion sous contrainte —

Partie 9: Préparation et utilisation des éprouvettes préfissurées pour essais sous charge croissante ou sous déplacement croissant

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 7539-9 was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*.

ISO 7539 consists of the following parts, under the general title *Corrosion of metals and alloys — Stress corrosion testing*:

— *Part 1: General guidance on testing procedures*

— *Part 2: Preparation and use of bent-beam specimens*

— *Part 3: Preparation and use of U-bend specimens*

— *Part 4: Preparation and use of uniaxially loaded tension specimens*

— *Part 5: Preparation and use of C-ring specimens*

— *Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement*

— *Part 7: Slow strain rate testing*

— *Part 8: Preparation and use of specimens to evaluate weldments*

— *Part 9: Preparation and use of pre-cracked specimens for tests under rising load or rising displacement*

Corrosion of metals and alloys — Stress corrosion testing —

Part 9:
Preparation and use of pre-cracked specimens for tests under rising load or rising displacement

1 Scope

1.1 This part of ISO 7539 covers procedures for designing, preparing and using pre-cracked specimens for investigating the susceptibility of metal to stress corrosion cracking by means of tests conducted under rising load or rising displacement. Tests conducted under constant load or constant displacement are dealt with in ISO 7539-6.

The term “metal” as used in this part of ISO 7539 includes alloys.

1.2 Because of the need to confine plasticity to the crack tip, pre-cracked specimens are not suitable for the evaluation of thin products such as sheet or wire and are generally used for thicker products including plate, bar and forgings. They can also be used for parts joined by welding.

1.3 Pre-cracked specimens may be stressed quantitatively with equipment for application of a monotonically increasing load or displacement at the loading points.

1.4 A particular advantage of pre-cracked specimens is that they allow data to be acquired from which critical defect sizes, above which stress corrosion cracking may occur, can be estimated for components of known geometry subjected to known stresses. They also enable rates of stress corrosion crack propagation to be determined.

1.5 A principal advantage of the test is that it takes into account the potential impact of dynamic straining on the threshold for stress corrosion cracking.

1.6 At sufficiently low loading rates, the K_{ISCC} determined by this method can be less than or equal to that obtained by constant load or displacement methods and can be determined more rapidly.

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.

ISO 7539-1:1987, *Corrosion of metals and alloys — Stress corrosion testing — Part 1: General guidance on testing procedures*

ISO 7539-6:—[1)], *Corrosion of metals and alloys — Stress corrosion testing —Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement*

1) To be published. (Revision of ISO 7539-6:1989)

ISO 7539-7:—[2)], *Corrosion of metals and alloys — Stress corrosion testing — Part 7: Slow strain rate testing*

ISO 11782-2:1998, *Corrosion of metals and alloys — Corrosion fatigue testing — Part 2: Crack propagation testing using precracked specimens*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7539-6 as well as the following apply.

3.1
rate of change of crack opening displacement at loading plane
$\dot{V}_{LL}$
deflection at the loading point access measured over a fixed period

3.2
stress intensity factor at crack initiation
$K_{I\text{-init}}$
stress intensity applied at the commencement of measurable crack growth

3.3
range of stress intensity factor
ΔK_f**, in fatigue**
algebraic difference between the maximum and minimum stress intensity factors in a cycle

3.4
displacement rate
dq/dt
rate of increase of the deflection either measured at the loading point axis or away from the loading line

4 Principle

4.1 The use of pre-cracked specimens acknowledges the difficulty of ensuring that crack-like defects, introduced during either manufacture or subsequent service, are totally absent from structures. Furthermore, the presence of such defects can cause a susceptibility to stress corrosion cracking, which in some materials (e.g. titanium) may not be evident from tests on smooth specimens under constant load. The principles of linear elastic fracture mechanics can be used to quantify the stress situation existing at the crack tip in a pre-cracked specimen or structure in terms of the plane strain-stress intensity.

4.2 The test involves subjecting a specimen, in which a crack has been developed from a machined notch by fatigue, to an increasing load or displacement during exposure to a chemically aggressive environment. The objective is to quantify the conditions under which environmentally-assisted crack extension can occur in terms of the threshold stress intensity for stress corrosion cracking, K_{ISCC}, and the kinetics of crack propagation.

4.3 Tests may be conducted in tension or in bending. The most important characteristic of the test is the low loading/displacement rate that is applied.

4.4 Because of the dynamic straining which is associated with this method, the data obtained may differ from those obtained for pre-cracked specimens with the same combination of environment and material when the specimens are subjected to static loading only.

2) To be published. (Revision of ISO 7539-7:1989)

4.5 The empirical data can be used for design or life prediction purposes in order to ensure either that the stresses within large structures are insufficient to promote the initiation of environmentally-assisted cracking at whatever pre-existing defects may be present or that the amount of crack growth which would occur within the design life or inspection periods can be tolerated without the risk of unstable failure.

4.6 Stress corrosion cracking is influenced by both mechanical and electrochemical driving forces. The latter can vary with crack depth, opening or shape because of variations in crack-tip chemistry and electrode potential and may not be uniquely described by the fracture mechanics stress intensity factor.

4.7 The mechanical driving force includes both applied and residual stresses. The possible influence of the latter should be considered in both laboratory testing and application to more complex geometries. Gradients in residual stress in a specimen may result in non-uniform crack growth along the crack front.

4.8 K_{ISCC} is a function of the environment, which should simulate that in service, and of the conditions of loading.

5 Specimens

5.1 General

5.1.1 A wide range of standard specimen geometries of the type used in fracture toughness tests may be used. Those most commonly used are described in ISO 7539-6. The particular type of specimen used will be dependent upon the form, the strength and the susceptibility to stress corrosion cracking of the material to be tested and also on the objective of the test.

5.1.2 A basic requirement is that the dimensions be sufficient to maintain predominantly triaxial (plane strain) conditions in which plastic deformation is limited in the vicinity of the crack tip. Experience with fracture toughness testing has shown that for a valid K_{Ic} measurement, both the crack length, a, and the thickness, B, shall be not less than

$$2{,}5\left(\frac{K_{\mathrm{Ic}}}{R_{\mathrm{p0,2}}}\right)^2$$

and that, where possible, larger specimens where both a and B are at least

$$4\left(\frac{K_{\mathrm{Ic}}}{R_{\mathrm{p0,2}}}\right)^2$$

shall be used to ensure adequate constraint.

From the view of fracture mechanics, a minimum thickness from which an invariant value of K_{ISCC} is obtained cannot currently be specified. The presence of an aggressive environment during stress corrosion may reduce the extent of plasticity associated with fracture and hence the specimen dimensions needed to limit plastic deformation. However, in order to minimize the risk of inadequate constraint, it is recommended that similar criteria to those employed during fracture toughness testing used regarding specimen dimensions, i.e. both a and B shall be not less than

$$2{,}5\left(\frac{K_{\mathrm{I}}}{R_{\mathrm{p0,2}}}\right)^2$$

and preferably shall be not less than

$$4\left(\frac{K_\text{I}}{R_{\text{p0,2}}}\right)^2$$

where K_I is the stress intensity to be applied during testing, in MPa/m.

As a test for its validity, the threshold stress intensity value eventually determined shall be substituted for K_I in the first of these expressions.

5.1.3 If the specimens are to be used for the determination of K_{ISCC}, the initial specimen size shall be based on an estimate of the K_{ISCC} of the material (in the first instance, it being better to over-estimate the K_{ISCC} value and therefore use a larger specimen than may eventually be found necessary). Where the service application involves the use of material of insufficient thickness to satisfy the conditions for validity, it is permissible to test specimens of similar thickness, provided that it is clearly stated that the threshold intensity value obtained, K_{QSCC}, is of relevance only to that specific application. Where it is required to determine stress corrosion crack growth behaviour as a function of stress intensity, the specimen size should be based on an estimate of the highest stress intensity at which crack growth rates are to be measured.

5.1.4 A wide choice of specimen geometries is available to suit the form of the test material, the experimental facilities available and the objectives of the test. Two basic types of specimen can be used

a) those intended for being loaded by means of a tensile force;

b) those intended for being loaded by means of a bending force.

This means that crack growth can be studied under either bend or tension loading conditions. The specimens can be used for either the determination of K_{ISCC} by the initiation of a stress corrosion crack from a pre-existing fatigue crack using a series of specimens and for measurements of crack growth rates. Since the specimens are loaded during exposure to the test environment, the risk of unnecessary incubation periods is avoided.

5.1.5 Crack length measurements can be readily made with a number of continuous monitoring methods such as the electrical resistance technique.

5.1.6 Bend specimens can in principle be tested in relatively simple cantilever beam equipment but specimens subjected to tension loading require a tensile test machine.

5.2 Specimen design

5.2.1 The specimens can be subjected to either tension or bend loading. Depending on the design, tension loaded specimens can experience stresses at the crack tip which are predominantly tensile (as in remote tension types such as the centre-cracked plate) or contain a significant bend component (as in crackline loaded types such as compact tension specimens). The presence of significant bending stress at the crack tip can adversely affect the crack path stability during stress corrosion testing and can facilitate crack branching in certain materials. Bend specimens can be loaded in 3-point, 4-point or cantilever bend fixtures.

5.2.2 The occurrence of crackline bending with an associated tendency for crack growth out of plane can be curbed by the use of side grooves.

5.2.3 A number of specimen geometries have specific advantages, which have caused them to be frequently used for rising load/displacement stress corrosion testing. These include:

a) compact tension (CTS) specimens, which minimize the material requirement;

b) cantilever bend specimens, which are easy to machine and inexpensive to test;

c) C-shaped specimens, which can be machined from thick walled cylinders in order to study the radial propagation of longitudinally oriented cracks.

Details of standard specimen designs for each of these types of specimen are given in Figures 1 to 3.

5.2.4 If required, e.g. if fatigue crack initiation and/or propagation is difficult to control satisfactorily, a chevron notch configuration as shown in Figure 4 may be used. If required, its included angle may be increased from 90° to 120°.

5.2.5 Where it is necessary to measure crack opening displacements, knife edges for the location of displacement gauges can be machined into the mouth of the notch, as shown in Figure 5a). Alternatively, separate knife edges can either be screwed or glued on to the specimen at opposite sides of the notch, as shown in Figure 5b). Details of a suitable tapered beam displacement gauge are given in Figure 6.

5.3 Stress intensity factor considerations

5.3.1 It can be shown, using elastic theory, that the stress intensity, K_{I}, acting at the tip of a crack in specimens or structures of various geometries can be expressed by relationships of the form

$$K_{\mathrm{I}} = Q \times \sigma \times \sqrt{a}$$

where

Q is a dimensionless geometrical constant;

σ is the applied stress in MPa;

a is the crack length in metres.

5.3.2 The solutions for K_{I} for specimens of particular geometry and loading method can be established by means of finite element stress analysis, or by either experimental or theoretical determinations of specimen compliance.

5.3.3 K_{I} values can be calculated by means of a dimensionless stress intensity coefficient, Y, related to crack length expressed in terms of a/W through relationship of the form

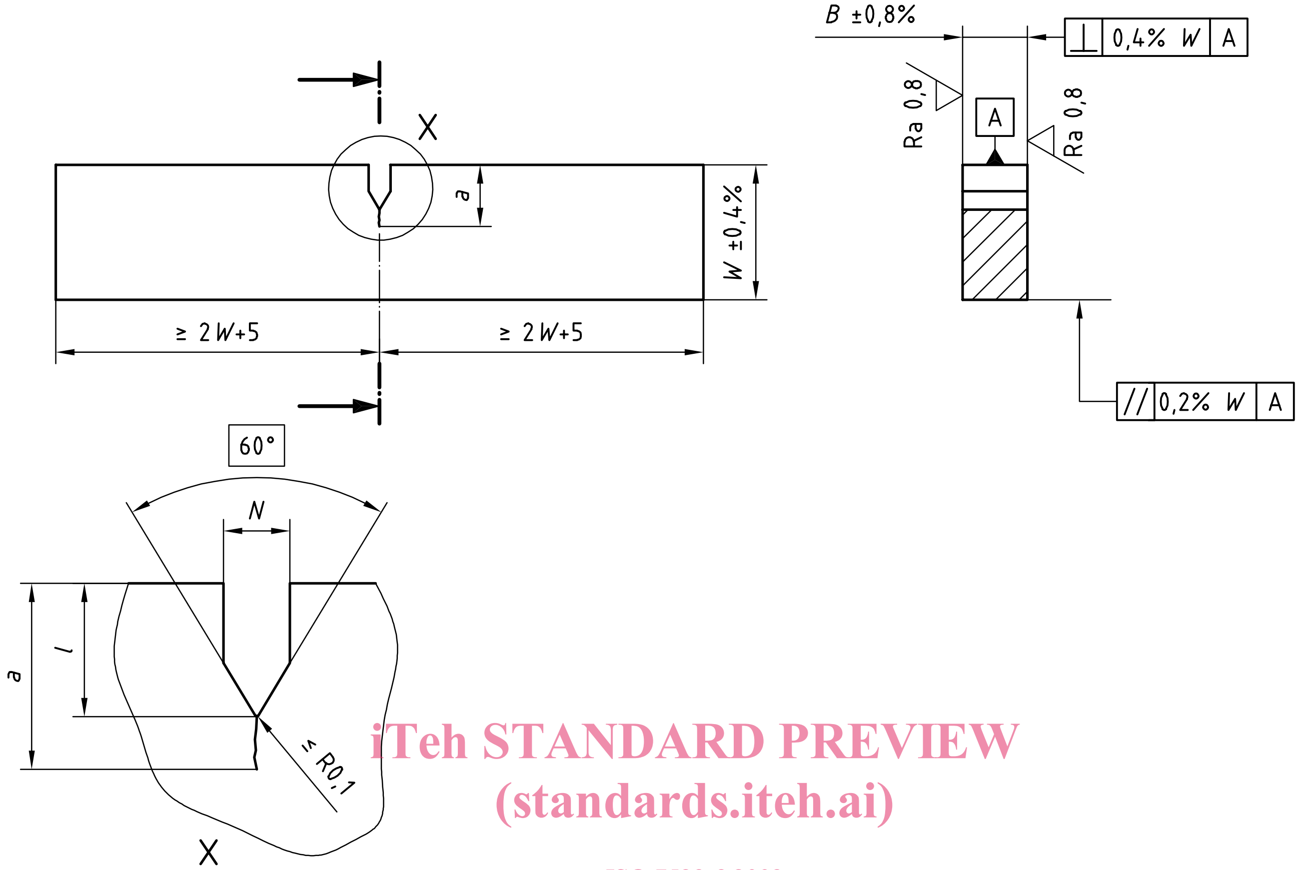
$$K_{\mathrm{I}} = \frac{YP}{B\sqrt{W}}$$

for compact tension and C-shaped specimens, where W is the width of the specimen in metres and P the applied load.

5.3.4 Where it is necessary to use side-grooved specimens in order to curb crack branching tendencies, etc., shallow side grooves (usually 5 % of the specimen thickness on both sides) can be used. Either semi-circular or 60° V-grooves can be used, but it should be noted that even with semi-circular side grooves of up to 50 % of the specimen thickness, it is not always possible to maintain the crack in the desired plane of extension. Where side grooves are used, the effect of the reduced thickness, B_{n}, due to the grooves on the stress intensity can be taken into account by replacing B with $\sqrt{BB_{\mathrm{n}}}$ in the above expression. However, the influence of side grooving on the stress intensity factor is far from established and correction factors should be treated with caution, particularly if deep side grooves are used.

5.3.5 Solutions for Y for specimens with geometries which are often used for stress corrosion testing are given in Figures 7 to 9.

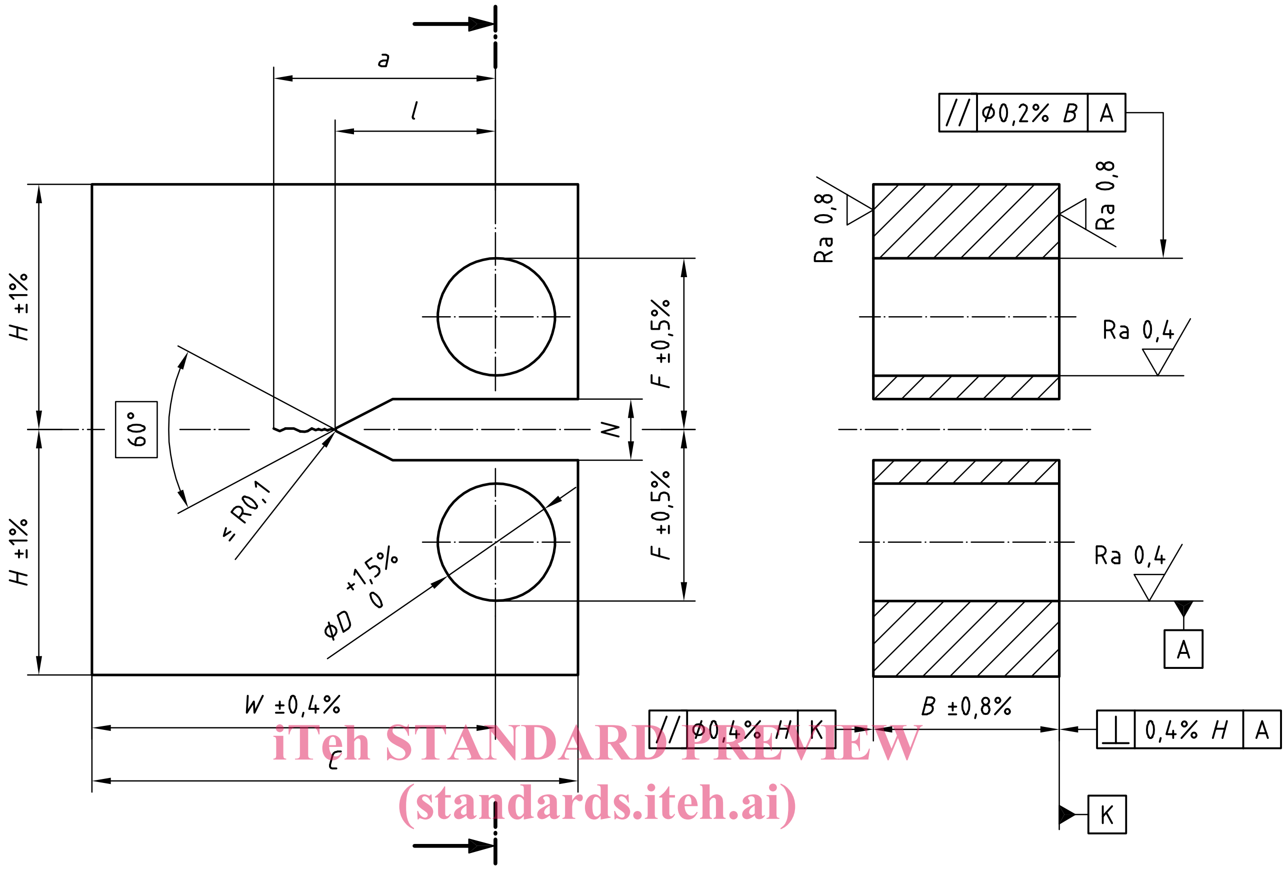
Dimensions in millimetres



Width	= W
Thickness, B	= 0,5 W
Notch width, N	= 0,065 W maximum (if $W > 25$ mm) or 1,5 mm maximum (if $W \leqslant 25$ mm)
Effective notch length, l	= 0,25 W to 0,45 W
Effective crack length, a	= 0,45 W to 0,55 W

Figure 1 — Proportional dimensions and tolerances for cantilever bend test pieces

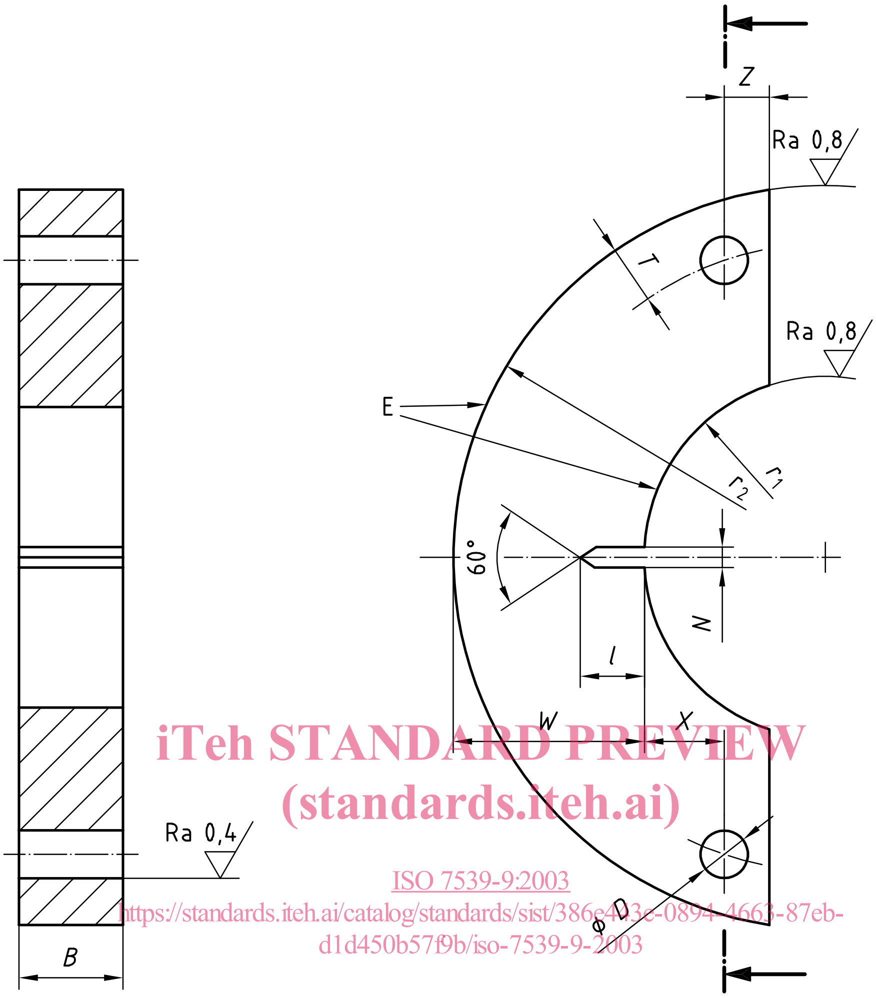
Dimensions in millimetres



Net width	= W
Total width, C	= 1,25 W minimum
Thickness, B	= 0,5 W
Half height, H	= 0,6 W
Hole diameter, D	= 0,25 W
Half distance between hole outer edges, F	= 1,6 D
Notch width, N	= 0,065 W maximum
Effective notch length, l	= 0,25 W to 0,40 W
Effective crack length, a	= 0,45 W to 0,55 W

Figure 2 — Proportional dimensions and tolerances for compact tension test pieces

Dimensions in millimetres



Net width	= W
Thickness B	= 0,50 $W \pm$ 0,01 W
Axis of holes to tangent to inner radius, X	= 0,50 $W \pm$ 0,005 W
Notch width, N	= 1,5 mm minimum (0,1 W maximum)
Notch width, I	= 0,3 W
Axis of holes to face of specimen, Z	= 0,25 $W \pm$ 0,01 W
Axis of holes toouter surface, T	= 0,25 $W \pm$ 0,01 W
Diameter of holes, D	= 0,25 $W \pm$ 0,005 W

NOTE All surfaces should be perpendicular and parallel, as applicable, to within 0,002 W TIR and “E” surfaces perpendicular to “Y” surfaces to within 0,02 W TIR:

Figure 3 — Proportional dimensions and tolerances for C-shaped test pieces