

Method for

Determination of the dynamic fracture toughness of metallic materials

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Foreword

This British Standard has been prepared under the direction of the Iron and Steel and the Non-Ferrous Metals Standards Committees.

Methods are described for determining the crack opening displacement and the plane strain fracture toughness of metallic materials at loading rates greater than those described in BS 5762:1979 and BS 5447:1977. Fracture toughness measurements made at these high rates of loading are referred to as dynamic fracture toughness measurements.

The methods described require relatively elaborate facilities and special equipment. However, the method described in the main body of the text is considered by the Committee to have had sufficient use to merit its adoption as a standard method, although new developments and refinements can be expected to emerge in the future.

Significant interest centres upon a more readily applied method that will serve to provide an approximate assessment of the dynamic toughness of materials for comparative purposes up to higher rates than those covered by this standard. The method given in Appendix A is not regarded yet as being sufficiently developed for use as a definitive standard, but has however been included for the guidance of users.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

SAFETY NOTE. It is important to note that tests of the type described involve the use of large forces and rapidly moving test pieces and machine parts. The safety of machine operators has to be considered when these high rate dynamic determinations are made.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 36, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This British Standard describes procedures for assessing the crack opening displacement (COD)¹⁾ and the plane strain fracture toughness (K_{Ic}) of metallic materials at loading rates that cause rates of increase in stress intensity factor between 80 and $10^5 \text{ N mm}^{-1.5} \text{ s}^{-1}$ ²⁾ and rates of increase of crack opening displacement of less than 150 mm/s.

Appendix A describes a shorter procedure for dynamic fracture toughness determinations. This method has not been sufficiently developed for use as a definitive standard but has been included for the guidance of users.

Appendix B describes recommended methods for checking the adequacy of response of recording devices to the dynamic events occurring in the relevant determinations.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard the following definitions apply.

2.1

stress intensity factor (K_I)

the elastic stress field intensification at the tip of a crack subjected to an opening mode

NOTE It is a function of applied force, crack length and test piece geometry, having units of stress $\times$ length^{0.5}.

2.2

plane strain fracture toughness (K_{Ic})

a property of a material indicative of the material's resistance to crack growth under conditions of high constraint to plastic deformation and in which plastic deformation is limited. It is the critical value of K_I at which the first significant extension of the crack occurs when it is under the influence of a rising force

2.3

stress intensity coefficient (Y)

a coefficient derived from stress analysis of the particular test piece geometry and crack length

2.4

fatigue stress intensity factor (K_f)

the plane strain stress intensity factor corresponding to the maximum force of the fatigue cycle during the final stage of fatigue crack growth, that is the last 1.25 mm or 2.5 % of the effective test piece width (W), whichever is the greater

2.5

effective crack length (a)

the notch length (M) plus fatigue crack length

NOTE See Figure 1, Figure 2 and Figure 5.

3 Symbols and designations

For the purposes of this British Standard the following symbols and designations apply.

NOTE This is not a complete list. Some symbols which are only used once are defined where they occur.

Symbol Designation

a effective crack length

B test piece thickness

E Young's modulus of elasticity at the temperature of interest

f_1 electrical frequency at which the output signal amplitude is reduced by 10 %

f_2 electrical frequency at which the output signal amplitude is reduced by 30 %

¹⁾ In this British Standard the term COD refers to the crack tip opening displacement. The latter is alternatively referred to by the term CTOD. The terms are synonymous.

²⁾ $0.0316 \text{ MN m}^{-1.5} = 1 \text{ N mm}^{-1.5} = 0.0316 \text{ MPa m}^{0.5}$.

Symbol	Designation
K_f	fatigue stress intensity factor for a crack subjected to an opening mode
K_I	stress intensity factor for a crack subjected to an opening mode
$\dot{K}_I$	rate of change of K_I with time
K_{Ic}	critical value of K_I
M	effective notch length
N	notch width
P	general symbol for applied force
$\dot{P}$	rate of change of force with time
P^a	general symbol for the applied force corresponding to the value of V_p or t_p
P_A	applied force at which the nominal stress equals $\frac{B \sigma_{y2} (W-a)^2}{S}$
P_c	applied force, where there is no evidence that stable ductile tearing has occurred, before either: a) fracture, or b) onset of arrested brittle crack^b
P_f	fatigue precracking force
P_i	applied force at which stable ductile tearing commences
P_m	applied force at the maximum force plateau on the force versus crack mouth opening gauge plot
P_u	applied force, where there is evidence that stable ductile tearing has occurred, before either: a) fracture, or b) onset of arrested brittle crack
R	fatigue force ratio, i.e. the algebraic ratio between minimum and maximum load in the fatigue cycle
S	distance between outer loading points of the test piece
T	test temperature
t_e	time interval for elastic extension during fracture toughness determination
t_f	test piece failure time interval
t_p	time interval for plastic deformation of the test piece
t_r	rise time interval
V_g	crack mouth opening gauge displacement
V_p	plastic component of crack mouth opening gauge displacement corresponding to P_i , P_c , P_u or P_m in Figure 12
W	effective test piece width
Y	general symbol for stress intensity coefficient
Y_1	stress intensity coefficient for bend test pieces
Y_2	stress intensity coefficient for tensile test pieces
y	half the distance between knife edge clamping points
Z	distance of crack mouth opening gauge location from test piece surface
δ	general symbol for crack opening displacement

^a In this British Standard the term COD refers to the crack tip opening displacement. The latter is alternatively referred to by the term CTOD. The terms are synonymous.

^b This is often colloquially described as a “pop-in”.

Symbol	Designation
$\dot{\delta}$	rate of change of crack opening displacement with time
δ_c	crack opening displacement, where there is no evidence that stable ductile tearing has occurred before either: a) fracture, or b) onset of arrested brittle crack^a
δ_i	crack opening displacement at which stable ductile tearing commences
δ_m	crack opening displacement at first attainment of maximum force plateau
$\dot{\delta}_p$	rate of change in the plastic component of crack opening displacement with time
δ_u	crack opening displacement, where there is evidence that stable ductile tearing has occurred, before either: a) fracture, or b) onset of arrested brittle crack
$\dot{\epsilon}$	strain rate to be applied during the determination of the dynamic 0.2 % proof stress
Δ	loading point displacement
$\dot{\Delta}$	velocity of the test piece at the central loading point
Δ_p	loading point displacement during plastic deformation of the test piece
ν	Poisson's ratio
σ_y	0.2 % proof stress at the temperature of the fracture toughness test
σ_{y1}	0.2 % proof stress at the temperature of the fatigue precracking procedure
σ_{y2}	0.2 % proof stress measured at the temperature and rate of loading of the determination

^a This is often colloquially described as a "pop-in".

4 Principle

The determination involves the development of a crack which is then caused to propagate by the application of tensile or bending forces which increase within controlled limits.

The following two stages are involved in the determination.

- a) A fatigue crack is first developed at the bottom of a machined notch by the application of a cyclic load.
- b) The crack is then caused to propagate by applying a monotonically increasing tensile or bending force.

The objective is to determine the displacement measured by the crack mouth opening gauge and the force at which the fatigue crack begins to extend or has extended by a specified amount.

Crack opening displacement is derived from the recorded data. The applied force is plotted against displacement as measured with a crack mouth opening gauge (see 7.2.1) and the displacement corresponding to the critical point on this curve is related to the crack tip opening displacement by means of a theoretical calibration.

The same method is used to obtain plane strain fracture toughness values. The limiting amount of crack growth can be established from the force/crack mouth opening gauge displacement record by means of a given deviation from linearity. The plane strain fracture toughness can then be calculated.

5 Test pieces

5.1 Test pieces for the measurement of crack opening displacement

Where no specific value is given in a product specification, the thickness (B) of the machined test pieces shall be as thick as is practically possible. The test piece shall be of one of the geometries illustrated in Figure 1 and Figure 2 (i.e. test piece A or B), and of sufficient length for it to be tested by bending over three loading points that have a total span of 4 times the test piece width (W). The type of test piece used to measure the crack opening displacement shall be stated, since the result is often specific to the type of test piece.

The notch on the test piece (as shown in Figure 1 and Figure 2), shall be such that the total included angle from the tip of the fatigue crack to the notch surface does not exceed 30° as shown in Figure 3. Machining requirements for accommodating integral type knife edges and details of attached knife edges are as illustrated in Figure 4.

The ratio of the distance between the knife edge clamping points ($2y$) to the test piece width (W), $2y/W$, shall not exceed 0.5.

5.2 Test pieces for the measurement of plane strain fracture toughness

5.2.1 The test piece size shall be chosen having regard to either:

- an estimate of the K_{Ic} of the material (in the first instance, it being better to overestimate the K_{Ic} value and therefore to use a larger test piece than may eventually be necessary), or
- the ratio of 0.2 % proof stress to Young's modulus.

NOTE Recommended values for thickness and crack length are given in Table 1.

5.2.2 Test pieces of either of the geometries shown in Figure 1 and Figure 5 shall be used.

5.2.3 The requirements of test piece size for a valid K_{Ic} measurement are that both the crack length (a) and the thickness (B) shall be not less than

$$2.5 \left(\frac{K_{Ic}}{\sigma_{y2}} \right)^2$$

NOTE To take account of uncertainties such as underestimation of the probable K_{Ic} value and the possibility of the determination not meeting some of the other validity criteria, it is recommended that, if possible, larger test pieces should be used, e.g. effective crack length (a) and specimen thickness (B) should both be at least:

$$4 \left(\frac{K_{Ic}}{\sigma_{y2}} \right)^2$$

5.2.4 The proportional dimensions and tolerances for Figure 1 test pieces are shown in Figure 1 and for Figure 5 test pieces are shown in Figure 5. A typical series of dimensions of Figure 5 test pieces is given in Table 2.

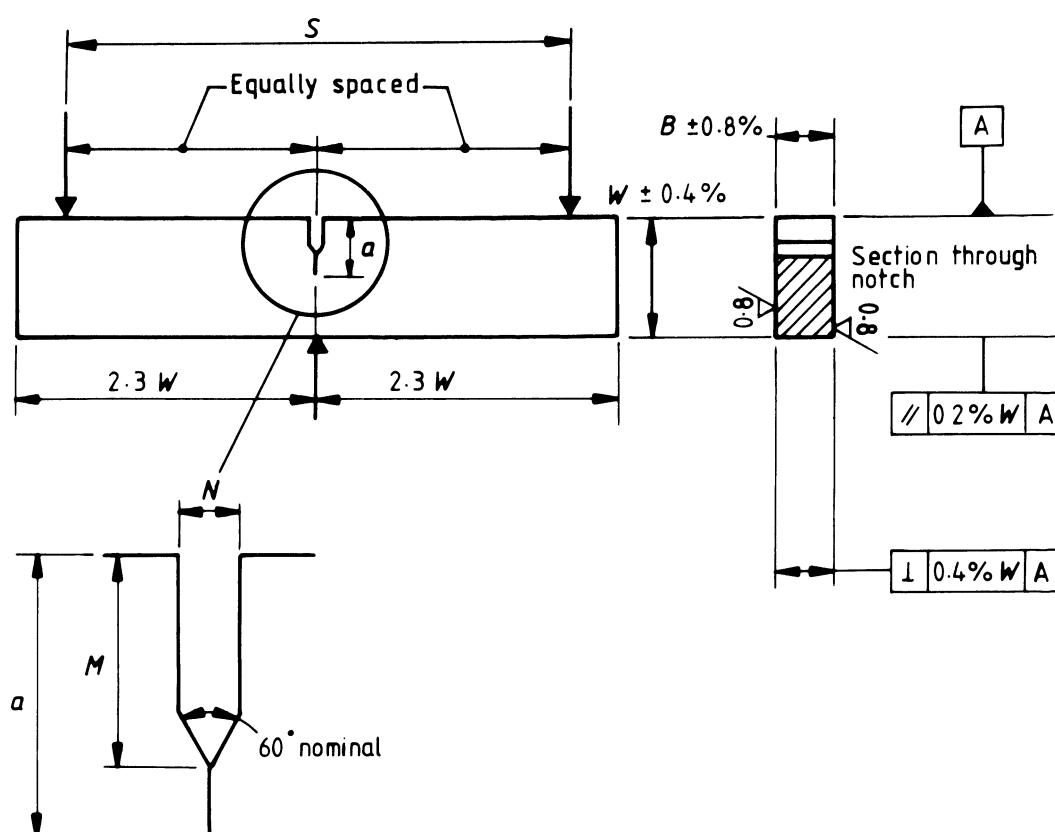
Table 1 — Recommended thickness and crack length of test pieces used for the measurement of plane strain fracture toughness

Ratio $\frac{\sigma_{y2}}{E}$		Recommended thickness and crack length
Over	Up to and including	
		mm
	0.0050	100
0.0050	0.0057	75
0.0057	0.0062	63
0.0062	0.0065	50
0.0065	0.0071	38
0.0071	0.0080	25
0.0080	0.0095	13
0.0095		6.5

Table 2 — Typical series of Figure 5 test piece dimensions

All dimensions are in millimetres.

Test piece dimension	Values of dimensions for various thicknesses (<i>B</i>)				
	13	25	50	75	100
<i>D</i>	$6.5^{+0.1}_{-0}$	$12.5^{+0.2}_{-0}$	$25.0^{+0.4}_{-0}$	$37.5^{+0.6}_{-0}$	$50.0^{+0.8}_{-0}$
<i>F</i>	10.40 ± 0.05	20.00 ± 0.10	40.00 ± 0.20	60.00 ± 0.30	80.00 ± 0.40
<i>N</i>	1.7 max.	3.25 max.	6.5 max.	9.75 max.	13.0 max.
<i>M</i>	6.5 to 10.4	12.5 to 20.0	25.0 to 40.0	37.5 to 60.0	50.0 to 80.0
<i>C</i>	32.5 min.	62.5 min.	125.0 min.	187.5 min.	250.0 min.
<i>W</i>	26.00 ± 0.10	50.00 ± 0.20	100.00 ± 0.40	150.00 ± 0.60	200.00 ± 0.80
<i>B</i>	13.00 ± 0.10	25.00 ± 0.20	50.00 ± 0.40	75.00 ± 0.60	100.00 ± 0.80
<i>H</i>	15.60 ± 0.15	30.00 ± 0.30	60.00 ± 0.60	90.00 ± 0.90	120.00 ± 1.20



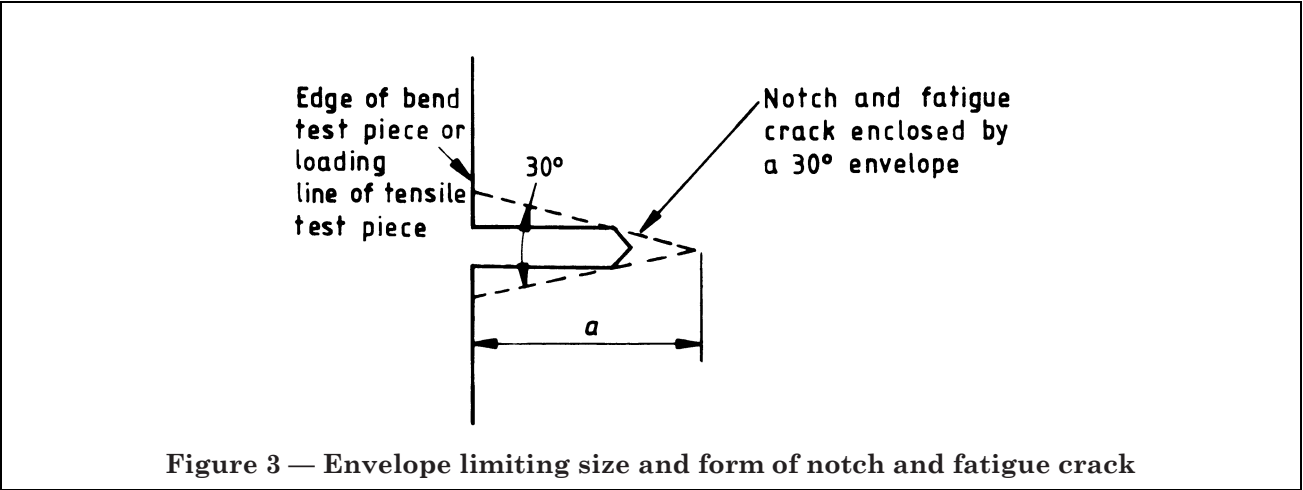
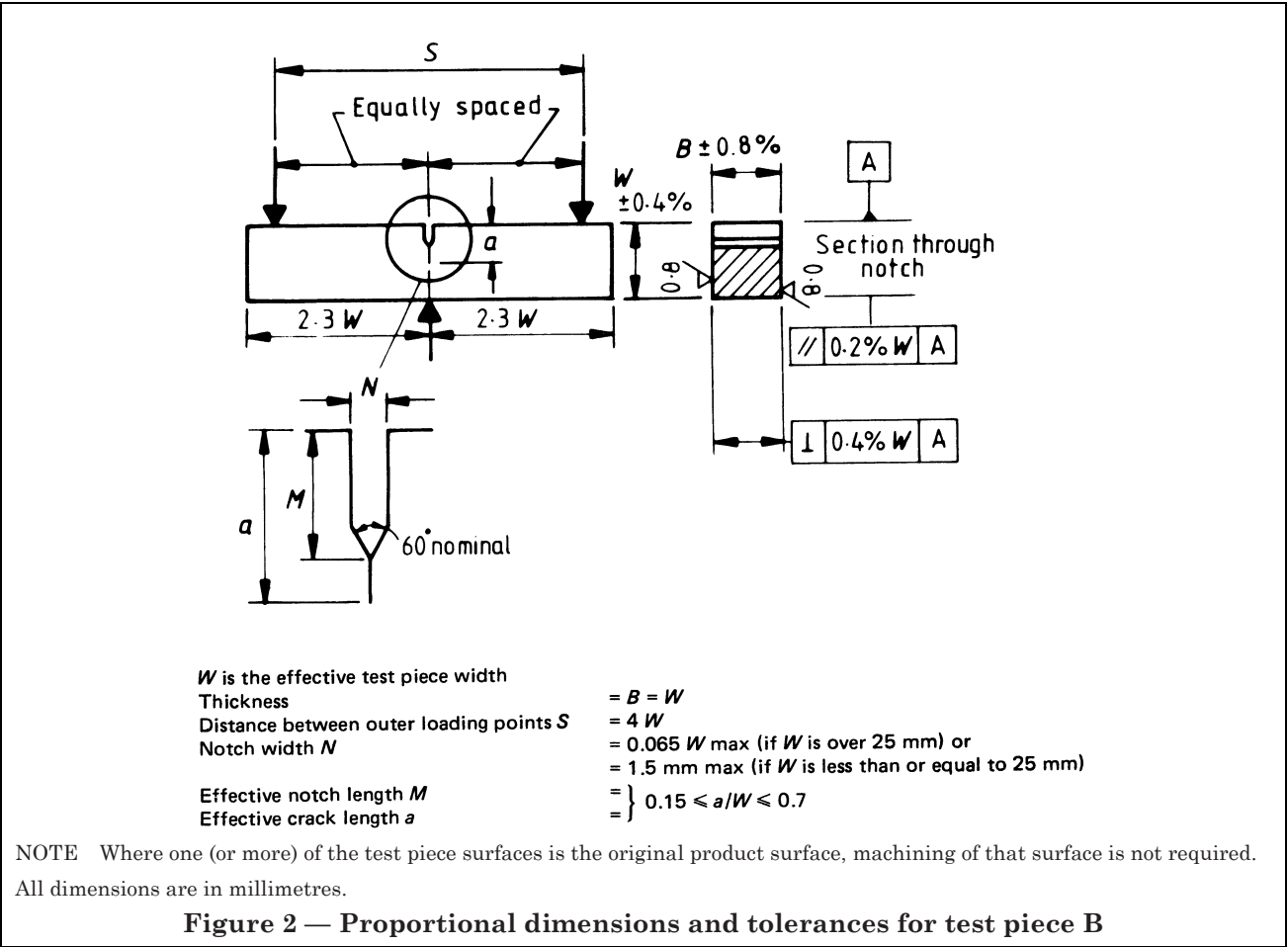
W is the effective test piece width
 Thickness
 Distance between outer loading points *S*
 Notch width *N*

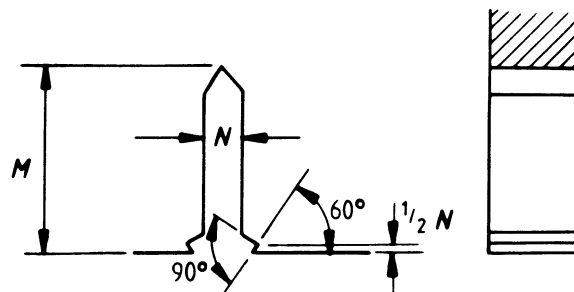
Effective notch length *M*
 Effective crack length *a*

$B = 0.5 W$
 $= 4 W$
 $= 0.065 W$ max (if *W* is over 25 mm) or
 $= 1.5$ mm max (if *W* is less than or equal to 25 mm)
 $= 0.25 W$ to $0.45 W$
 $= 0.45 W$ to $0.55 W$

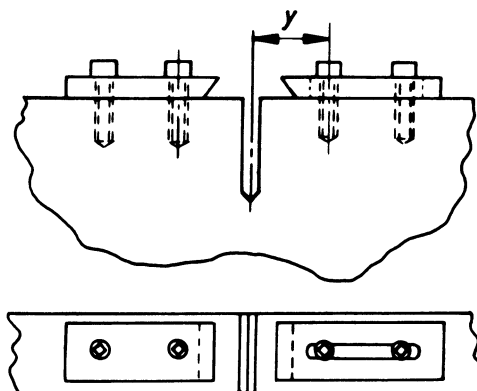
NOTE Where one (or more) of the test piece surfaces is the original product surface, machining of that surface is not required.
 All dimensions are in millimetres.

Figure 1 — Proportional dimensions and tolerances for test piece A





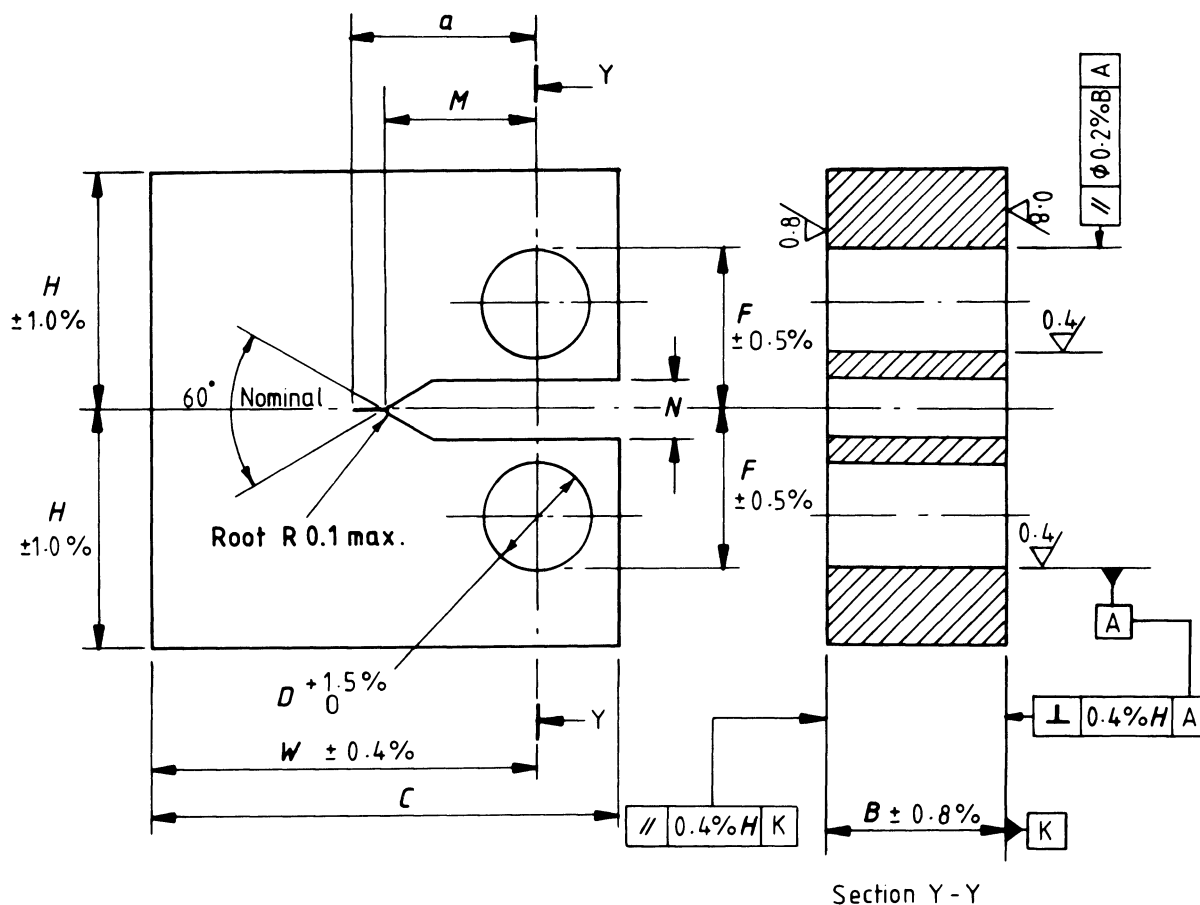
(a) Integral type



(b) Screw-on type

NOTE Provided adequate strength can be ensured, the above knife edges may be fixed with adhesive. Then y becomes the distance between the bottom edge of the knife edge and the centreline of the notch.

Figure 4 — Knife edges for location of crack mouth opening gauges



W is the effective test piece width

Total width C	$= 1.25 W \text{ min.}$
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	$= 0.065 W \text{ max.}$
Effective notch length M	$= 0.25 W \text{ to } 0.40 W$
Effective crack length a	$= 0.45 W \text{ to } 0.55 W$

All dimensions are in millimetres.

Figure 5 — Proportional dimensions and tolerances for test piece when determinations are made by applying a tensile force