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Metallic Materials –

Determination of Plane-Strain Fracture Toughness

(ISO 12737:2005, MOD)

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Metallic Materials –
Determination of Plane-Strain Fracture Toughness

1 Scope

This Standard specifies the method for determining the plane-strain fracture toughness of the homogeneous metallic materials using a specimen that is notched and pre-cracked by fatigue and subjected to slowly increasing crack displacement force.

2 Normative References

The provisions in following documents become the provisions of this Standard through reference in this Standard. For dated references, the subsequent amendments (excluding corrigendum) or revisions do not apply to this Standard, however, parties who reach an agreement based on this Standard are encouraged to study if the latest versions of these documents are applicable. For undated references, the latest edition of the referenced document applies.

GB/T 8170 Rules of Rounding off for Numerical Values

GB/T 12160 Calibration of Extensometers Used in Uniaxial Testing (GB/T 12160-2002, idt ISO 9513:1999)

GB/T 16825.1 Verification of Static Uniaxial Testing Machines – Part 1: Tension/Compression Testing Machines - Verification and Calibration of the Force-Measuring System (GB/T 16825.1-2002, idt ISO 7500-1:1999)

GB/T 20832 Metallic Materials - Designation of Test Specimen Axes in relation to Product Texture (GB/T 20832-2007, ISO 3785-2006, IDT)

3 Terms and Definitions

The following terms and definitions are applicable to this Standard.

3.1 Plane-strain stress intensity factor (K_I)

Magnitude of the elastic stress field at the tip of the crack subjected to opening mode displacement (Mode I).

NOTE 3: For chevron notch: suggested notch root radius 0.025 mm maximum. Notch tip angle 90° maximum, $A = C$ within 0.01W. Fatigue crack shall emerge on both surfaces of specimen.

Figure 2 – Crack Starter Notches and Maximum Permissible Notch/Crack Envelope

6 Apparatus

6.1 Testing machine and force measurement

The testing machine shall be calibrated in accordance with GB/T 16825.1 and shall be of at least grade 1. The testing machine shall have provisions for automatic recording of the force applied to the specimen; alternatively, a computer data acquisition system may be used to record force and displacement for subsequent analysis. The combination of force-sensing device and recording system shall permit, so that the force F_Q (as defined in Clause 10) to be determined from the test diagram with the accuracy of ± 1%.

6.2 Fatigue cracking preparation

When possible, the fatigue machine and force-indicating device shall be calibrated statically in accordance with GB/T 16825 and shall have a grade of at least 2. If the machine cannot be calibrated statically, the error of applied force shall be known to no greater than ± 2.5 %. Careful alignment of the specimen and test device is necessary to encourage straight fatigue cracks. The installment of test device shall be such that the stress distribution is uniform across the specimen thickness and symmetrical about the plane of the prospective crack.

6.3 Extensometer

The extensometer output shall represent the relative displacement of accuracy positions on two sides of the notch mouth. The design of the extensometer and knife edges shall allow free rotation of the points of contact between the extensometer and the knife edges.

The extensometer shall be calibrated in accordance with GB/T 12160, and shall be of at least grade 1; however, calibration shall be performed at least weekly during the time the extensometer is in use. Periodic verification of greater frequency may be required, depending on use and agreement between contractual parties.

Verification of the extensometer shall be performed at the temperature of test to ±5°C. The response of the extensometer shall correspond to the calibration apparatus to ±

environmentally-conditioned state. Normally, specimens shall also be machined in this final state. However, for material that cannot be machined in the final condition, the final treatment may be carried out after machining, provided that the required specimen dimensions are met; however, the specimen dimension tolerance, shape and surface roughness shall meet the requirements (see Figures B.1 and C.1), and that full account is taken of the effects of specimen size on metallurgical condition induced by certain heat treatments, e.g. water quenching of steels.

7.3.2 Crack-plane orientation

The fracture toughness of a material is usually dependent on the orientation and direction of propagation of the crack in relation to the principal directions of metal working, grain flow or otherwise-produced texture. Orientation of the crack plane shall be decided before machining (see 7.3.3), identified in accordance with the prescribed coordinate systems (see 3.3) and recorded (see Clause 11).

7.3.3 Machining

Specimen sizes, shapes. dimensional tolerances and surface finishes shall be as given in Figures B.1 and C.1.

7.3.4 Fatigue precracking

Fatigue precracking normally shall be done at room temperature with the specimen in the finally heat-treated, mechanically-worked or environmentally-conditioned state in which it is to be tested. Different fatigue precracking temperatures and intermediate thermal/mechanical/environmental treatments between fatigue precracking and testing shall be used only when such treatments are necessary to simulate the conditions for a specific structural application; and required dimensions and tolerances on specimen size and shape can be maintained. Such fatigue precracking shall be performed according to the requirements of Appendix A.

8 Test Program

8.1 Specimen measurement

Measure specimen thickness (*B*) to the nearest 0.025 mm or to 0.1%, whichever is larger, at not less than three equally spaced positions along the anticipated crack extension path. Take the average of these measurements as the thickness.

Measure specimen width (*W*) to the nearest 0.025 mm or to 0.1%, whichever is larger, at not less than three positions near the notch location. Take the average of these measurements as the width (*W*). For the compact tensile specimen, measure the width from the plane of the centerline of the loading pin holes.

average width *f* of the central flat fracture portion shall be measured between the crack tip and the unflagged edge of the specimen; record the proportion of oblique fracture per unit thickness $(B - f)/B$. (C) type fracture is full oblique fracture.

9 Test Procedures

If a recorder is used, adjust its magnification ratio properly such that the slope of the linear portion of the force-displacement record is between 0.85 and 1.5. Alternatively, if a computer data acquisition system is used, program it to capture enough data to allow the calculations in Clause 10. In either case, the concluding requirement of 6.1 shall be satisfied.

Load the specimen such that the rate of increase of stress intensity is between 0.5 $MPam^{1/2}/s$ and 3.0 $MPam^{1/2}/s$. Continue the test until the specimen can sustain no further increase in applied force. Record the maximum force (F_{max}).

10 Calculation and Interpretation of Test Results

If a recorder is used, the conditional value F_Q shall be determined as follows. Draw the secant line OF_5 (see Figure 4) from the point O with slope $(F/V)_5 = 0.95\ (F/V))_0$, where $(F/V))_0$ is the slope of the tangent *OA* to the linear portion of the record. The force F_Q is then defined as follows: if the force at every point on the record which precedes F_5 is lower than F_5 (type I), then $F_Q = F_5$. If, however, there is a maximum force (F_{max}) greater than preceding F_5 and which exceeds it (type II or type III), then this maximum force is equal to F_Q.

If a computer data acquisition system is used, the data reduction program shall determine the same forces (F_Q and F_{max}) as above. The algorithms for doing this are left to the discretion of the user.

Calculate the ratio F_{max}/F_Q, where F_{max} is the maximum force. If this ratio does not exceed 1.10, proceed to calculate K_Q as described in Appendix B or C, as appropriate. If the ratio exceeds 1.10, the test is not a valid K_{Ic} test. Calculate the value $2.5(K_Q/R_{p0.2})^2$. If this quantity Is less than the specimen thickness, the crack length and the ligament size, then K_Q is equal to K_{Ic}; otherwise, the test is not a valid K_{Ic} test.

The test result of plane-strain fracture toughness K_{Ic} shall be retained for three significant figures.

11 Test Report

The test report shall include at least the following information:

Appendix A

(Normative)

Fatigue Precracking of K_{Ic} Fracture Toughness Specimens

The object of fatigue precracking is to produce a sharp crack which is not affected by details of the precracking procedure. The following requirements will accomplish this objective:

A.1 Fixtures

The fixtures recommended for fracture testing are also suitable for fatigue precracking. If other fixtures are used, the K_I-calibration shall be performed with error no greater than 5%.

A.2 Specimen requirements

Fatigue precracking shall be conducted in accordance with 7.3. To facilitate precracking at a low level of stress intensity, specimen-notch root radius shall be as prescribed in 7.2.4.

A.3 Fatigue precracking procedure

Fatigue precracking may be conducted under either force control or displacement control. The ratio of cyclic minimum stress to maximum stress (R) shall not exceed 0.1. If K_Q equals to effective K_{Ic} result, then the maximum stress intensity factor during fatigue precracking shall not exceed 80% of the K_Q value. In the final phase of fatigue precracking (2.5% of crack length of a), K_f shall not exceed 60% of K_Q. If fatigue precracking and fracture testing are conducted at different temperatures, K_f shall not exceed $0.6[(R_{p0.2})_p/(R_{p0.2})_t]K_Q$, where $(R_{p0.2})_p$ and $(R_{p0.2})_t$ are the specified offset yield strengths $R_{p0.2}$ at the fatigue precracking and test temperatures, respectively.

2 – reference point using tip extensometer to measure the loading point, see E.2.2.1.

NOTE: the axis of the loading hole shall be tangential to the inner diameter with deviation no greater than 0.005*W*.

Figure E.1 – Standard Proportion and Tolerance of C-Shaped Tensile Specimen

E.2 Test equipment

E.2.1 Tensile test clevis can see D.2.

E.2.2 Extensometer's provisions can refer to 4.2.

E.2.2.1 For C-shaped tensile specimen with X/W =0.5, other method can be taken to measure the displacement, which is shown in Figure E.1 (a). Prepare two cone-shaped indentations at the midpoint of the intersection between plane where loading hole centerline located and r_1 inner circle surface of the specimen; insert the tip extensometer into the indentation to measure the displacement between loading points. The used extensometer shall meet the requirements of 4.2.

E.2.2.2 For C-shaped tensile specimen, as long as the standard length ≤$W/2$, the crack mouth opening displacement is irrelevant to the standard length.

E.3 Test procedures

E.3.1 Dimension measurement

E.3.1.1 Measurement of *W*: close to the two sides of notch caused by fracture, measure ($r_2 - r_1$) at the midpoint of the thickness; accurate to 0.025mm or 0.1%*W* (whichever is larger); record the average of the two values as *W*. In addition, measure ($r_2 - r_1$) at another four positions (namely Point 1, 2, 3, 4 in Figure E.2); thereof, two shall be close to the loading hole as much as possible; the other two shall be near the arc midpoint between fracture surface and loading hole. If there is one difference between these four measurement values and *W* is greater than 10%, then such specimen shall be rejected or reworked.

E.3.1.2 Measurement of *X*: as shown in Figure E.2, measure the distance *d* on two sides of the specimen, accurate to 0.025mm or 1%*d*, whichever is larger. Use the average value of two measurement results to deduct *W*, their difference shall be recorded as *X*.

E.3.1.3 Measure the outer radius r_2, accurate within 5%. If it can't be measured directly, then measure the outer circle chord length *L* at the centerline of two loading holes as per the Figure E.3, accurate to within 5%. Calculate the average of r_2 by using this measurement value as per Formula (E.1) (see this NOTE).

F.2 Test equipment

F.2.1 Tensile test clevis can refer to Figure D.2.

F.2.2 Extensometer: the provisions on extensometer can refer to 6.3. For circular compact tensile specimen, as long as the standard length doesn't exceed 0.55*W*, the displacement is basically irrelevant to the standard length.

F.3 Test procedures

F.3.1 Dimension measurement, for the circular compact tensile specimen, the specimen roundness shall be measured in addition to the measurement of specimen width and crack length.

F.3.1.1 Before machining the specimen, the specimen blank's roundness shall be inspected. Measure the radius a the octantometric point of the circumference of the specimen blank, and one of the measurement points shall be located in the expected notch plane. Calculate the average value of these measurement results, record as *r*. if the difference between any measurement value and *r* is greater than 5%, machine the blank into the required roundness. And require $D = 2r = 1.35W$.

F.3.1.2 Based on the centerline of the loading hole, measure the width *W* and crack length *a* (the specimen notch edge can be regarded as the reference line during the actual measurement; but the measurement of *W* and *a*, it shall subtract the distance from centerline loading hole to the notch edge). Measure *W* at least three points close to the notch, accurate to 0.025mm or 1%*W* (whichever is larger), record the average value.

F.3.2 Circular compact tensile specimen test

Install clevis, the centerline deviation of the upper and lower loading rods shall be within 0.76mm; the specimen shall be at the center of the clevis with deviation within 0.76mm.

F.4 Calculation

K_Q of circular compact tensile specimen shall be calculated as per the following formula:

$$K_Q = (F_Q / BW^{1/2}) \times f(a/W) \qquad \text{(F.1)}$$

Where:

$$f(a/W) = \frac{(2 + a/W)[0.76 + 4.8(a/W) - 11.58(a/W)^2 + 11.43(a/W)^3 - 4.08(a/W)^4]}{(1 - a/W)^{3/2}}$$

------ The End ------