Annex E

Flaw Idealization and Flaw Re-characterization

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E.1 Flaw idealization

Crack shape idealisation becomes necessary for real cracks that have been detected in an inspection or are visible on a fractured face. Idealisation means that a flaw or crack showing a complex shape is modelled as one of the crack types of straight, elliptical, semi-elliptical or quarter-elliptical geometry. The flaws have to be characterised by the height and length of their containment rectangles, ellipses or semi-ellipses (see Figure E.1)

A special problem of crack shape idealisation exists when crack branching occurs. This is a common feature of stress corrosion cracking. In this case, from a fracture mechanics point of view, the idealised crack must be considered as being equivalent to a whole network of cracks. The recommended approach [E1] is illustrated in Figure E.2. In the first step, the network is idealised by a single planar crack, the dimensions of which are defined by the containment rectangle around the affected region. This is then rotated such that it is perpendicular to the maximum principle stress plane or, when the shear stresses cannot be neglected, treated as mixed mode (see paragraph 11.5).

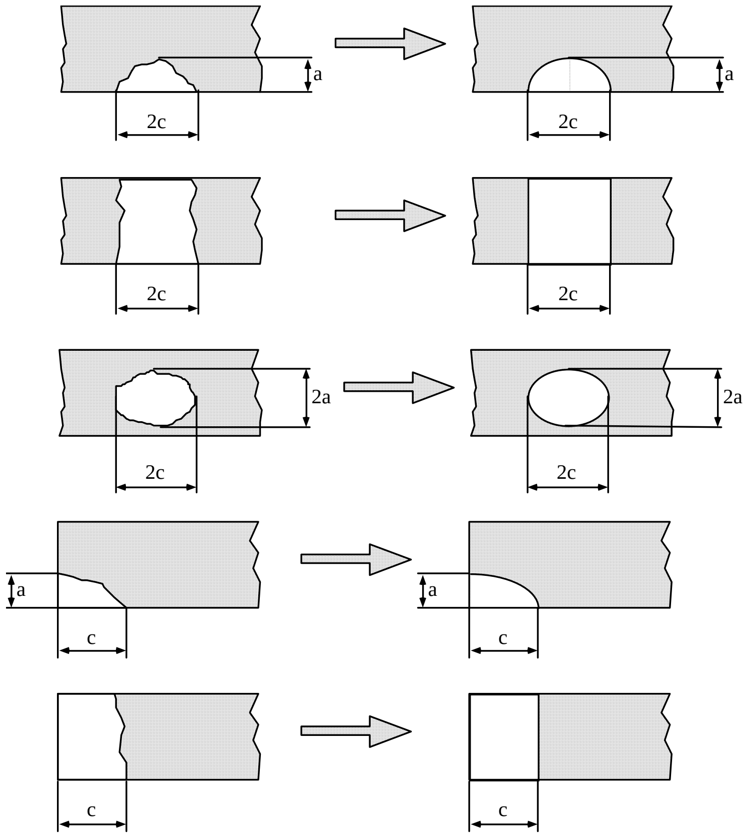

Figure E.1 – Flaw Shape Idealisation

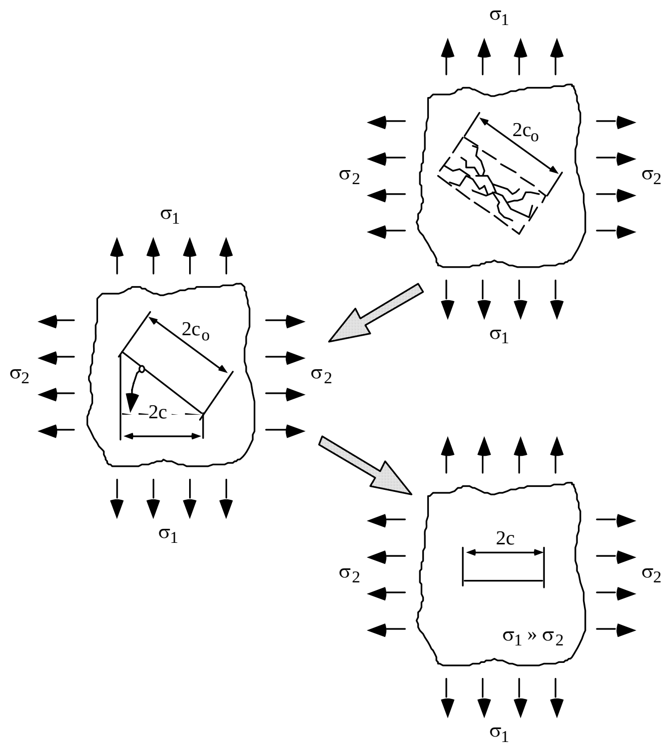

Figure E.2 – Treatment of Branched Cracks

E.2 Flaw orientation and projected flaw depth

In paragraph 5.3.1 it is explained that the loading is usually given as stress distribution across the wall section of the un-cracked structure. More specifically, the term "wall section" refers to a certain reference plane that, for the assessment, has still to be defined dependent on the real flaw orientation and/or the principal stress directions.

Frequently the crack will be aligned with the plane normal to the maximum principal stresses but there are exceptions, e.g. for anisotropic material behaviour or substantial shear stresses. If the plane of a real crack is not identical to one of the planes perpendicular to the principal stresses it has to be projected into such a plane (Figure E.3). Usually one of the possible projections will lead to a stress intensity factor and a limit load significantly higher than those for the other projections and small compressive or tensile principal stress components can be ignored. However, caution is advised in cases involving compressive hydrostatic stresses.

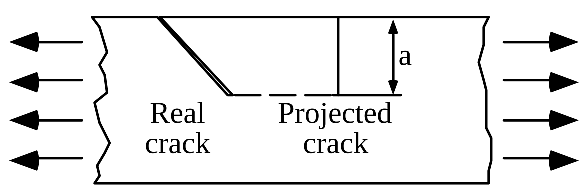

Figure E.3 - Projection of crack dimension for a crack at an angle to the applied stress

E.3 Flaw re-characterisation

When an embedded or a surface flaw cannot be assessed as tolerable, it is possible that, in some circumstances, the prediction of failure of a ligament may not be critical to the overall integrity of the structure or component. In such cases, a further assessment step may be carried out, in which the ligament concerned is assumed not to be present and the initial flaw is re-characterised as a surface or through thickness flaw, as appropriate. The resulting flaw may require an allowance to be made for dynamic conditions and for possible crack growth at the ends if ligament failure actually occurred.

(a) When ligament failure is predicted to occur by local yielding or it is known that ligament failure will be by a ductile mechanism (upper shelf operation) an allowance should be made for possible crack growth at the ends during ligament breakthrough. The size of the re-characterised flaw is calculated by increasing the total length of the original flaw, as shown in Fig. E.4

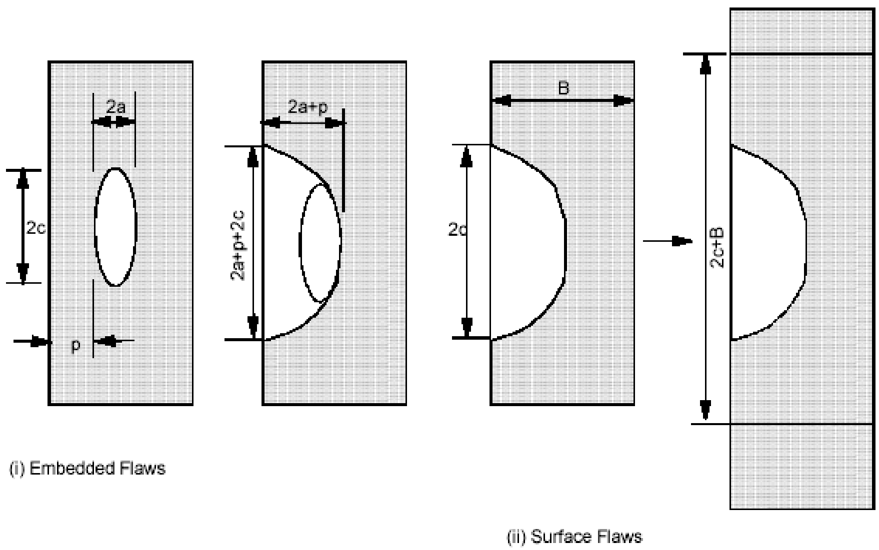

Figure E.4 – Re-characterisation of flaws for ligament failure by ductile mechanism.

It should be noted that re-characterisation of flaws is also required for leak-before-break assessments, although these are generally used to assess leak rates. The development of crack shapes by sub critical crack growth is shown in Fig. E.5 for surface cracks and Fig. E.6 for through-wall cracks as a function of crack length and loading mode. Recommended re-characterised dimensions are described in the description of leak-before-break procedures (see paragraph 11.2.3).

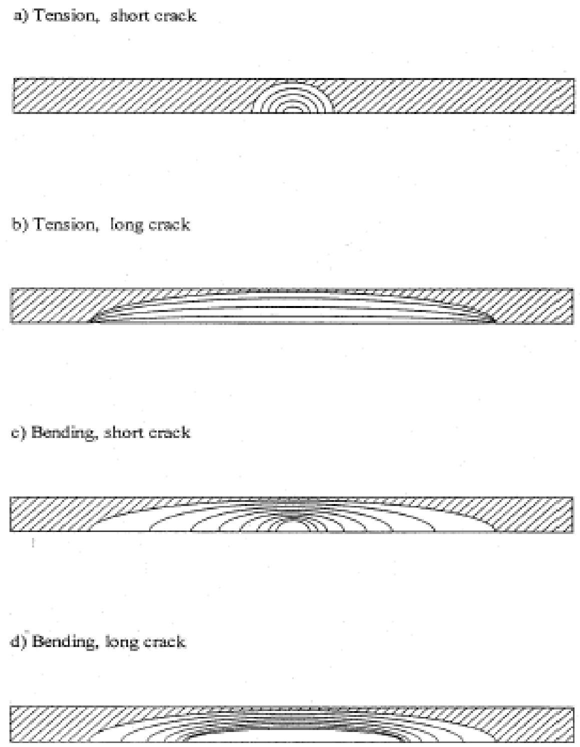

Figure E.5 – Developments of crack shapes for sub-critical surface crack growth.

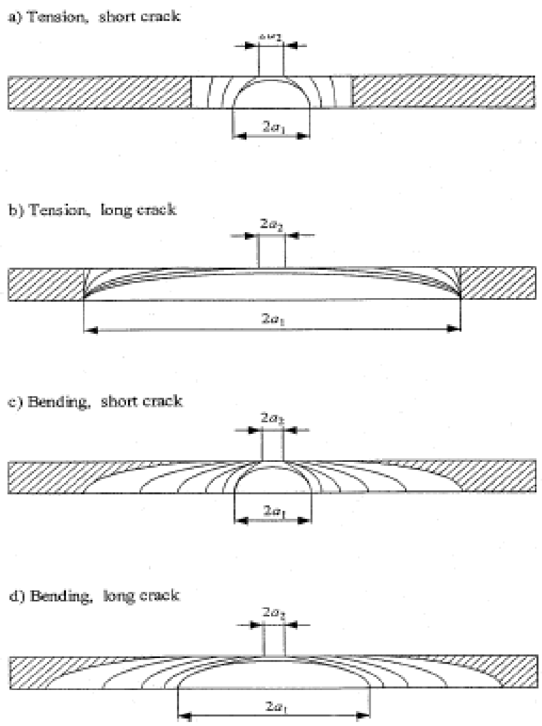

Figure E.6 – Developments of crack shapes for sub-critical through-wall crack growth.

(b) When an assessment indicates that ligament failure may occur and where this failure may be by a brittle mechanism (lower shelf or transition regime) an allowance should be made for possible dynamic conditions at the moving crack tip. The dimensions of the re-characterised flaw should be made as per Fig. E.4 but the fracture toughness used in the assessment of the re-characterised flaw should be dynamic or crack arrest toughness, appropriate for the material and temperature

The re-characterised flaw may then be assessed according to the current fracture assessment procedures. This procedure will only be of benefit if local conditions in the ligament are more severe than those of the re-characterised flaw. If the re-characterised flaw also fails the assessment, the initial flaw is not applicable.There are two reasons why a re-characterisation of a buried or embedded crack into a semi-elliptical surface crack or a semi-elliptical into a through-wall crack might become necessary.

a) Most available stress intensity factor solutions are not very exact or even undefined for small ligaments (the distance between the deepest point of the crack and the free surface).

b) The changeover from semi-elliptical surface to through-wall cracks is usually combined with a drop in the calculated crack driving force. This is an artefact due to the simultaneous changeover in the analysis from a "local" to a "global" limit load (see Paragraph 5.3.1.11.3) as the latter tends to be less conservative.

NOTE: *The re-characterised crack length at surface, 2c, is assumed to exceed the original 2c. This is because allowance is made for spontaneous brittle or ductile crack extension at the break through, e.g., due to dynamic effects [E2].*

E.4 Bibliography

[E.1] Fitness-for-Service, API Recommended Practice 579, First Edition, January 2000

[E.2] R6: 'Assessment of the integrity of structures containing defects', British Energy Generation Limited, Revision 4, June 2001.