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Corrosion of metals and alloys — Guidelines for assessing the significance of stress corrosion cracks detected in service

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National foreword

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Corrosion of metals and alloys — Guidelines for assessing the significance of stress corrosion cracks detected in service

*Corrosion des métaux et alliages — Lignes directrices pour évaluer
l'importance des fissures de corrosion sous contrainte détectées en
service*



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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.

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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.

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ISO 21601 was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*.

Corrosion of metals and alloys — Guidelines for assessing the significance of stress corrosion cracks detected in service

1 Scope

This International Standard provides guidelines on the appropriate steps to take when a stress corrosion crack has been detected in service and an assessment has to be made of the implications for structural integrity.

Such an evaluation should be made in the context of the perceived consequences of failure using appropriate risk-based management methodologies. Since this is application-specific, it is beyond the scope of this International Standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7539-6, *Corrosion of metals and alloys — Stress corrosion testing — Part 6: Preparation and use of precracked specimens for tests under constant load or constant displacement*

ISO 7539-9, *Corrosion of metals and alloys — Stress corrosion testing — Part 9: Preparation and use of precracked specimens for tests under rising load or rising displacement*

3 Principle

When a crack is detected during a scheduled inspection programme, repair will in most cases be initiated in a relatively short time-scale, by removing the component or by cutting out the damaged section and re-welding. However, in some circumstances there may be limited opportunity for repair and a pressure to keep the system in operation until the next extended outage, to minimize lost production. In other applications, it may be considered that a crack can be tolerated, provided that there is an adequate framework for predicting the evolution of the crack, defining inspection intervals, and assessing the likelihood of failure. Such an evaluation may be incorporated with an assessment of the consequences of failure into a risk-based inspection methodology. The challenges faced in living with the crack for a short or long period are establishing when the crack started, relating this to service conditions including transients (i.e. assessing whether the crack would be growing 'continuously' or only in response to specific fluctuations in service conditions), evaluating the mechanical driving force, characterizing the state of material through which the crack initiated and will propagate, assessing the laboratory database and translating this to the perceived service operation conditions using fracture mechanics or other concepts.

Leak before break (LBB) may also need to be evaluated where there is the risk of explosive or catastrophic failure, but, in practice, stress corrosion is usually detected and repaired for operational reliability reasons.

The purpose of this International Standard is to provide guidance in developing a damage-assessment process with some guidance on measures to control growth rates.

4 Characterization of the nature and origin of the crack

A first step is to develop a complete physical assessment of the crack¹⁾ in terms of identifying its shape and dimensions (uncertainty in defect size assessment should be noted) as this will feed into any finite element/fracture mechanics analysis. This should include an assessment of the crack location in relation to local stress concentrators, welds, crevices (e.g. at fasteners, flanges), and also the details of the crack path. If more than one crack is present, the crack density and the spacing between the cracks should be noted in view of possible future coalescence. Also, the state of the surface should be assessed for general or pitting corrosion damage.

Characterizing the crack as a stress corrosion crack may be possible from visible observation, e.g. significant crack branching (although extensive branching, albeit possibly beneficial, may preclude simple stress analysis and warrant removal of the crack). In most cases it is deduced from prior experience and awareness of the likelihood of other failure modes but recognizing that loading in service does not usually correspond to the simple static load tests conducted in the laboratory. Thus, there may be cyclic loading to some degree or dynamic straining associated with transient temperature changes. In many cases, distinction between a stress corrosion failure mechanism and a hydrogen embrittlement mechanism may not be possible. Where crack extension and remanent life assessment are the primary concerns, this may not be a critical issue provided that the laboratory data used for assessment relate to the particular service conditions. However, mitigation procedures can be contingent upon knowledge of the cracking mechanism.

Attention should be given to the operational history to assess the extent, if any, of system upsets that may have contributed to the onset of cracking.

5 Definition of service conditions and system history

5.1 Stresses

5.1.1 Operational stresses

Operational stresses are usually well known from the design process and, in practice, rarely critical except in the sense of being additive to residual fabrication stresses. However, a word of caution is needed. These are sometimes higher than they were designed to be due to discrepancies between the design drawings and the as-manufactured components as a consequence of inadequate control during manufacture. This can result in higher stresses than intended by designers where changes in section occur. For instance, the low pressure (LP) turbine shaft failures at Ferrybridge (1975)^[1] occurred because the radius of the centre-collar stress relief grooves was smaller than the design value as a result of poor machining.

Other problems can arise if machining score marks are not ground out, causing increased stresses locally and sites for localized corrosion.

5.1.2 Residual stresses

Residual stress characterization *in situ* in service may be undertaken by a variety of methods. X-ray diffraction (XRD) is most commonly used. However, since the depth of material sampled is less than 10 µm, rough surfaces can give misleading results. *In situ* neutron diffraction methods may be possible with some relatively portable components but it is expensive. Depth variation of residual stress can be obtained by incremental hole-drilling but this is destructive, albeit at a local level, and requires repair. There is more scope for evaluation of removable parts and here XRD and electrochemical polishing can also be used for depth profiling of residual stress. Non-destructive depth profiling of residual stress requires access to a synchrotron radiation source and by implication is limited to removable parts. In the

1) Detection of the crack in the first instance may have been by a range of methods including ultrasonic testing, acoustic emission, visual inspection, dye penetration, electromagnetic and potential drop methods. More detailed information on crack shape and size may be derived from X-ray tomography, though confined to removable parts and potentially size limited.

absence of measurement, the residual stress may be assumed to be at the effective yield strength (taking into account multi-axial stress state) for the parent material or weld metal, as appropriate, according to the location. However, the yield stress needs to be carefully evaluated in the light of the work-hardening capacity of the material and likely extent of local deformation. For critical applications, mock-ups may be necessary for the evaluation of residual stresses and cold work by X-ray diffraction. Post-weld heat treatment should relieve residual stress but it may not always be performed fully or adequately. Hydrotesting of pipes or vessels may also relieve the residual stress, by an amount proportional to the applied pressure stress (e.g. Hewerdine et al.^[2]). Since stress corrosion crack growth rates are often stress intensity factor (K) independent or weakly dependent on K in the Stage II region (see [Clause 7](#)) there may be some latitude in characterizing the residual stress for analysis above K_{ISCC} (KISCC: Mode I threshold stress intensity factor for stress corrosion cracking) but recognizing that there will be uncertainty in calculating the critical flaw size for unstable fracture.

5.1.3 Multi-axial stresses

Multi-axial stresses are usually dealt with by determining the maximum principal tensile stress direction and assuming that stress corrosion cracks grow perpendicular to that direction. In fact, this is certainly an oversimplification and remains an area requiring further study. Isolated studies have shown that the biaxial or triaxial stress state should not be ignored.

5.1.4 Transients (e.g. thermal transients)

The usual concern with thermal transients is that they superimpose a cyclic load on the static stresses, which may enhance the risk of cracking as described later. In addition, larger thermal transients typically associated with start-up or shut-down of a plant will introduce significant dynamic loading for significant periods which again can enhance the risk of cracking (see later).

5.1.5 Corrosion product wedging

Since the oxidized forms of common structural metals occupy a significantly larger volume than the metal from which they came, possible additional loading due to wedging cannot be ignored in crevices or growing cracks. In practice, only a few circumstances are known where this is practically important and usually arises where there is a significant occurrence of crevice corrosion.

5.2 Service environment

5.2.1 General

Intended service environments are normally well characterized (temperature, water chemistry, partial pressure of gases, total pressure) but lack of operator objectivity as to possible environmental transients is a serious handicap in many service failure investigations.

5.2.2 Excursions from normal operating conditions

The probability of a leaking condenser, ion-exchange failure, residue from chemical cleaning, cooling water failure (giving temperature rise), oxygen ingress etc. all require objective assessment and wishful thinking on the part of plant operators in this respect is a serious handicap to finding practical solutions. The operational history should be examined carefully to assess the extent to which excursions occurred.

The concern with a transient increase in temperature or change in service environment is that it may move the system into a domain for activation of stress corrosion cracking (SCC), which would otherwise not be a concern. Thus, in assessing the significance of a crack, the exposure history should be examined and the extent of available data for predicting the likelihood of growth and the growth rate at the normal temperature or chemistry following an excursion evaluated. Often, the data are limited.