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On the re-characterisation of defects in structural integrity assessments due to snap-through

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Abstract

TAGSI was asked by HSE/NII to comment on the effectiveness of the R6 procedure which permits a surface defect failing an initial assessment to be re-assessed as a through thickness defect of increased length. If the defect passes the re-assessment it may then be considered acceptable.

In TAGSI's view re-characterisation needs to be considered separately for contained plastic collapse and ductile or brittle fracture of the remaining ligament. For plastic collapse and ductile tearing of the remaining ligament the R6 rules for re-characterisation appear generally satisfactory. For brittle failure of the ligament in many cases the R6 recommendations will be found satisfactory but for cases of large difference between static and dynamic toughness it is recommended that scoping calculations should be carried out for the defect geometry, loading and material properties of concern.

Keywords: Defect; Re-characterisation; Snap-through

1. Introduction

TAGSI was asked to respond to the following question, put by HSE/NII.

> 'R6 Section 9.3.2 suggests that on snap through the crack length should be increased by amounts that depend on the circumstances. Does TAGSI agree that these are conservative assumptions for un-irradiated and irradiated pressure vessel steels?
>
> During the work TAGSI are asked to indicate what factors they consider should be taken into account in estimating margins of safety which involve assumptions about change in length on snap through.
>
> In addition are there any re-characterisation rules for part penetration defects that propagate and arrest but remain part penetrating.'

The question was considered firstly by a Task Group and then by the full TAGSI Committee. The Group held four meetings, on 11th November 1997, 7th January, 29th April and 3rd September 1998. Membership of the Task Group is shown in Appendix A. Despite the time interval since the response by TAGSI was produced, it is considered to be of sufficient interest that it should be published in the open literature.

2. Discussion

If an initial assessment of a surface or embedded defect proves unacceptable due to local conditions in the remaining ligament, the R6 procedure permits further consideration by assuming that the ligament concerned has failed and investigating whether the resulting through thickness or surface defect is then acceptable. Examples of surface and embedded defects and their dimensions are shown in Fig. 1. This procedure is known as re-characterisation and is divided into different categories depending on whether ligament failure is expected to occur by a brittle mechanism or by a ductile mechanism. For

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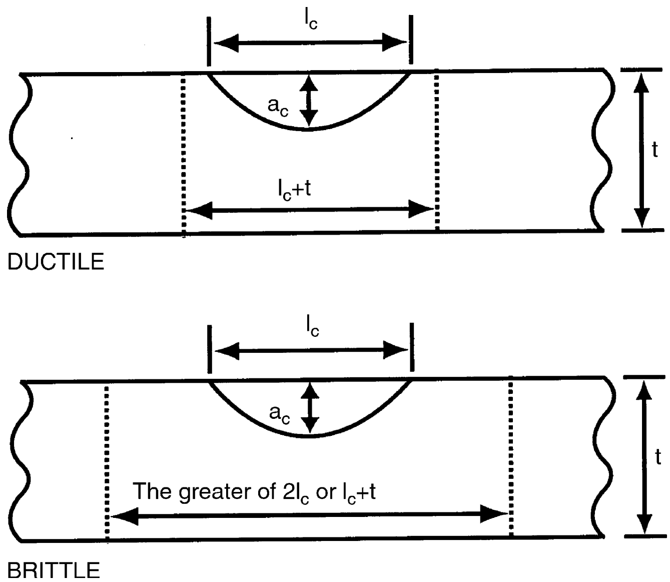

Fig. 1. R6 flaw re-characterisation.

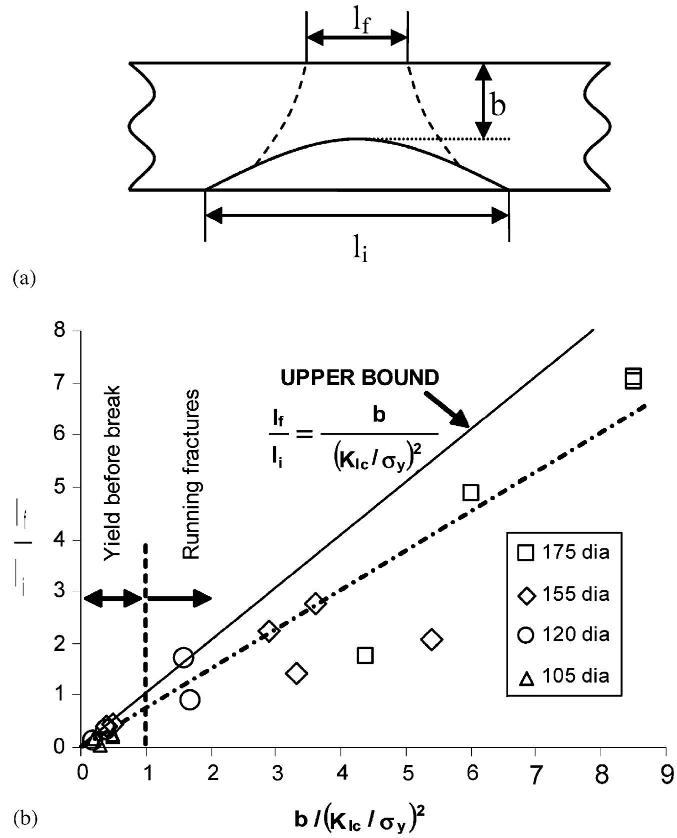

Fig. 2. (a) Break through of a crack in gun barrel tests. (b) Results of the gun barrel tests [5].

brittle mechanisms (e.g. cleavage fracture) a surface defect is re-characterised as a through wall defect with length the larger of twice its original length or the original length plus the thickness. For ductile mechanisms (e.g. ductile tearing or plastic collapse of the ligament) the surface defect is re-characterised as a through wall defect with length equal to the original length plus the thickness.

It was decided firstly to try to establish the original basis for the R6 requirements and then to seek out relevant theoretical and experimental evidence to form a view of the requirements. It appears that the original requirements were based primarily on the judgment and experience of those involved in formulating the R6 procedures [1]. Re-characterisation requirements somewhat similar to those in R6 are also present in the parallel BSI Document PD 6493 now BS7910:2005, although these were based on considerations of plastic collapse of the ligament and the increased crack tip severity which would occur there rather than on permitting failure of the ligament by fracture.

Experimental work reported by Formby [1] concluded that critical crack sizes for running cracks were smaller than for static cracks in quenched and tempered steels at room temperature. For cracks running from brittle to tough zones he concluded on energy balance grounds that the running crack would stop only if the width of the brittle zone was less than half the static critical crack size.

Experimental evidence is also available from a series of high strain cyclic loaded tests on pipework [2] (IPIRG-2), from wide plate tests carried out by AEA Technology [3] and from a series of pressure vessel tests carried out by CEGB in the 1960s [4]. The pipework tests had shown that when part thickness defects had broken through the wall by ductile mechanisms they had remained stable with no significant increase in surface length until further cycles of loading were applied after break through. The wide plate tests had shown that the crack length on the back face had increased rapidly after breakthrough to catch up with the front face but snap through had occurred in a stable manner as far as the crack length on the front face was concerned. The pressure vessel tests provided some data on when fractures initiated in the ligament arrested and when continued propagation occurred.

Further experimental work by Underwood et al. [5] on high strength steel gun tubes of varying external diameter (120–175 mm) containing semi elliptical cracks at the inside surface showed cases where, on snap-through by ductile fracture, the crack did not propagate beyond the original surface crack length even though the cracks would have been judged unstable on the basis of the R6 re-characterisation rules. Underwood et al. have suggested that a critical parameter was the ratio of the ligament to notional plastic zone size, $b/(K_{Ic}/\sigma_Y)^2$, where b is the ligament, K_{Ic} is the plane strain fracture toughness and σ_Y is the yield strength. Fig. 2(a) shows an initial semi elliptical surface crack of length l_i breaking through a ligament, b, to form a crack of length l_f on the opposite surface. This final crack length after ductile tearing failure (l_f), could be less than or greater than the initial surface crack length l_i. The results of the tests are summarised in Fig. 2(b). The solid line