INFLUENCE OF THE CONFIGURATION OF RECONSTITUTED SPECIMENS ON FRACTURE TOUGHNESS CHARACTERISATION OF PRESSURE VESSEL STEELS

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Specimen reconstitution techniques offer the possibility to obtain fracture toughness measurements when only small amounts of material are available. In order to obtain extra information from Charpy specimens, an electron-beam weld reconstitution method is established to obtain Compact Tension specimens from the broken halves of Charpy specimens. The validity of the fracture toughness characterisation is analysed by comparing J_R-resistance curves of specimens with insert and those of normalised specimens without insert.

INTRODUCTION

In view of nuclear power plant life extension efforts it is desirable to obtain a direct measurement of the pressure vessel toughness. The operational limits for the reactor are based on the relative measurement of embrittlement assessed with the transition curves obtained using Charpy specimens from surveillance capsules incorporated in the reactor. These limits, as an indirect measurement of toughness, are unduly conservative (1). The surveillance capsules do not include fracture mechanics specimens that can determine elastic-plastic properties of the irradiated material. Therefore a specimen reconstitution technique is developed to obtain Compact Tension specimens (CT) from the broken halves of Charpy specimens. Of all the possible configurations of reconstituted CT specimens obtained by inserting broken halves of Charpy specimens, the two configurations studied in this paper are represented in Figure 1:

- CT specimens with a nominal thickness of 10 mm, a bar insert of 24x10x10 mm and one transversal weld seam, denominated type-B.
- CT specimens with a nominal thickness of 10 mm, a cubic insert of 10x10x10 mm, one transversal and two longitudinal weld seams, denominated type-C.

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The advantage of type-B is weld geometry simplicity. However, only two orientations can be studied. With the configuration of type-C all orientations can be studied by rotating the 10x10x10 mm insert.

MATERIAL

Two pressure vessel steels are used in this study: the forged SA 508 Cl.3 steel, denominated MF in this paper, and the plate material SA 533 Gr.B Cl.1, denominated ML. The chemical composition and the tensile properties are given in Table 1.

TABLE 1 - Chemical Composition and Tensile Properties

Material	Element	C	Si	Mn	P	S	Cr	Mo
ML	wt %	0.20	0.22	1.44	0.008	0.007	0.16	0.49
MF	wt %	0.19	0.19	1.45	0.005	0.001	0.12	0.52

Material	Element	Ni	Al	Cu	V	Sn	N	As
ML	wt %	0.59	0.28	0.04	0.01	-	-	-
MF	wt %	0.78	0.019	0.04	0.003	0.004	0.0096	0.003

Material	Orientation	Yield Stress (MPa)	Tensile Strength (MPa)
ML	L	486	623
ML	T	521	636
MF	L	503	655
MF	T	505	646

SPECIMEN RECONSTITUTION AND PREPARATION

The CT specimens are reconstituted by electron-beam welding which satisfies the rigid requirements for reconstitution when only small amounts of insert material are available and therefore is suitable for reconstituting CT specimens (De Backer (2)).

Reconstituted CT specimens of the B-type with LS and LT orientations and those of the C-type with TL and TS orientations, all with a nominal thickness of 10 mm, are made to evaluate their validity. After welding, the reconstituted specimens are machined producing a reduction in the final nominal thickness. The support of the reconstituted CT specimens is always made of the ML steel, while the inserts are taken from either the ML or MF steel. The orientation of the insert and support is always the same. The orientations of the reconstituted configurations depend on the original Charpy specimens, in this case with an LT orientation. To compare the results normalised CT specimens, without insert and with a nominal thickness of 10 mm, are made using the same orientations and materials as the reconstituted specimens.

All the specimens are spark eroded from the base of the machined notch, until the transversal HAZ is crossed in the reconstituted ones. Then, the specimens are fatigue precracked until the initial crack length ratio (a_o/W) lies between 0.6 and 0.7. For the reconstituted specimens the obtained initial crack length is at least 1.6 mm beyond the transversal HAZ. All specimens are 20% side-grooved.

Before testing, the location and the extension of the HAZ is estimated by Vickers microhardness measurements and optical analysis of the weld seam. The average width of the HAZ is 2.1 mm at the weld face and 1.5 mm at the root for the C-type specimen. The welds of the B-type specimens are wider, the average width at the root is 2 mm and in some cases over 3 mm at the face.

EVALUATION OF THE FRACTURE TOUGHNESS CHARACTERISATION VALIDITY

The effect of the reconstitution technique and specimen configuration are assessed by comparing the J_R-curves of reconstituted and standard specimens. J_R-tests are performed using the unloading compliance technique. The tests are performed at room temperature. Afterwards the fracture surface is analysed by SEM and the plastic zone extension is estimated optically. The latter to verify if interference exists between the plastic zone and the HAZ of the weld seam. The optical method consists of heat tinting the specimen, slightly sanding its surface and observing it in a profile projector: the zone narrowed by plastic deformation is clearly outlined. The attempts made to estimate the plastic zone extension with microhardness measurements give a lot of scatter (2).

RESULTS AND DISCUSSION

B-type specimen configuration

The J_R-curves of the LS orientated ML material are represented in Figure 2, the other studied material and orientations give similar results. As in previous work (2) it is demonstrated that the J_R-curves obtained from reconstituted specimens of type-B correspond with those obtained from normalised specimens of the same thickness, although the HAZ width exceeded 3 mm. Bicego et al (3) successfully used the same configuration for 1 inch thick CT weld-reconstituted specimens. The J_R-curves are only valid for the thickness used, but nevertheless are useful for purposes of comparative analysis (2).

C-type specimen configuration

Two different cases are distinguished by comparing the J_R-curves obtained with reconstituted specimens of type-C with those of normalised CT specimens. Four tests are performed: two insert materials, ML and MF, and two orientations, TL and TS are used. In one of the four tests the J_R-curves coincide quite well. In the other three tests there is a sudden deviation of the J_R-curve of the reconstituted specimen after which the path of the J_R-curve reveals a less tougher behaviour. The two cases are represented in Figures 3 and 4, respectively.

Plastic zone extension and residual stresses

The optical method reveals that the plastic zone, at the surface of the specimen, does not reach the transversal weld in any of the tests of both B- and C-type specimen configurations. In spite of that, some of the transversal weld seams of the LS and LT specimens are wider.

In the first case of the C-type configuration the plastic zone does not reach the longitudinal welds either but in the three other tests the plastic zone abruptly stops at the HAZ boundary of the weld, as observed in tests with reconstituted Charpy specimens (Klausnitzer (4), van Walle et al (5)). The latter case, corresponding to Figure 4, is illustrated in Figure 5. Although the plastic zone inside the specimen will be smaller due to constraint, the interference gives a qualitative explanation for the observed deviation of the J_R-curves. When the plastic zone reaches the weld there is a reduction in the amount of plastic deformation associated with the volume of non deformable material. The constraint of the plastic deformation results in a lower energy absorption for further crack growth. As the plastic zone extension is very similar to the available undisturbed material area the width and exact location of the longitudinal weld seams is critical. It should also be observed that the plastic zone size will decrease when the insert material is embrittled by neutron irradiation.

Besides the interference of the plastic zone with the HAZ, residual welding stresses can play an influential role in the fracture toughness characterisation with reconstituted specimens (3). None of the mentioned factors seems to influence the fracture toughness characterisation with B-type reconstituted specimens. For the C-type the extension of the plastic zone is critical and residual tensile welding stresses probably play a role, because the insert has weld seams at opposite sides which is not the case with the B-type configuration. The interference is probably the cause of the deviation shown in Figure 4, while the slightly less tougher behaviour, observed in Figure 3, may be due to residual stresses.

The fracture surfaces observed in the corresponding specimens with or without insert show that the reconstitution technique does not affect the fracture mechanism, which in all cases is microvoid coalescence.

CONCLUSIONS

The fracture toughness can be characterised with reconstituted CT specimens with a nominal thickness of 10 mm, an insert of 24x10x10 mm from a broken Charpy specimen and one weld seam, for the thickness used.

The fracture toughness characterisation obtained from reconstituted CT specimens with a nominal thickness of 10 mm, an insert of 10x10x10 mm from a broken Charpy specimen and three weld seams can only be valid if there is no interference between the plastic zone and the weld. When the plastic zone develops its maximum width and reaches the HAZ the J_R-resistance curve deviates from the J_R-resistance curve obtained from normalised CT specimens.

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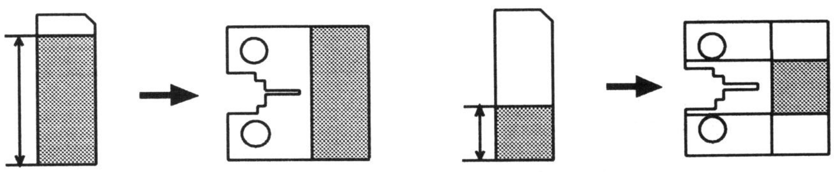

Figure 1 Configurations of reconstituted CT specimens

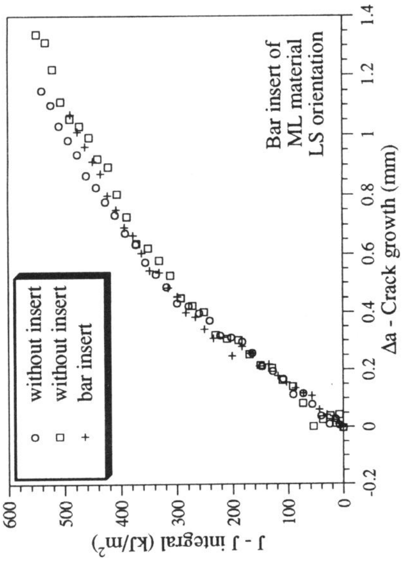

Figure 2 Comparison of JR-curves for bar insert

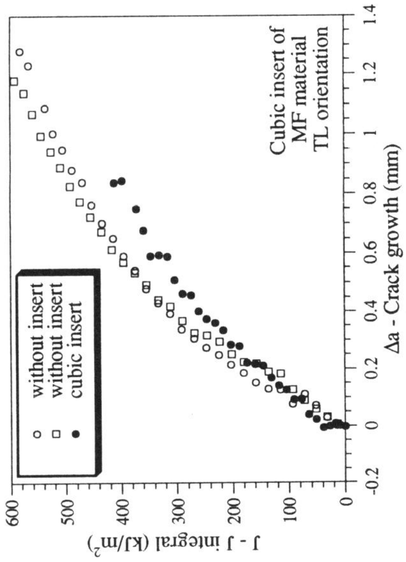

Figure 3 Comparison of JR-curves for cubic insert

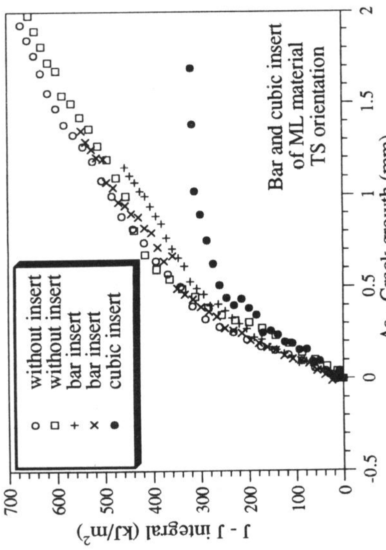

Figure 4 Comparison of JR-curves for bar and cubic inserts

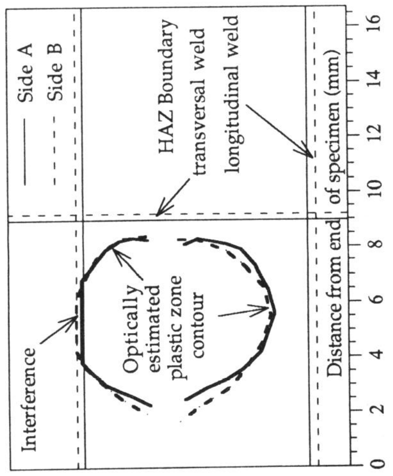

Figure 5 CT specimen with weld boundaries and plastic zone contour