COMPARISON OF J INTEGRAL BEHAVIOUR FOR THE TENSILE PANEL AND PRESSURE VESSEL

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Full-scale pressure vessel tests had been performed for an experimental analysis of crack behaviour by J integral direct measurement method, required after service cracking of spherical storage tanks produced of HSLA steel. In order to reduce next testing costs tensile panels with surface cracks had been tested in similar conditions to the full-scale pressure vessel model and the results for strains and J integral have been evaluated as comparable.

INTRODUCTION

Unexpected cracks occurred after several years of service in spherical storage tanks, produced by welding of high-strength low-alloy (HSLA) steel [1]. Detailed experimental analysis of service safety has been required for certain types of pressure vessels (e.g. for LPG storage). It had been found that crack initiation and propagation is depended on simultaneous or successive effects of geometrical imperfections (weldment misalignement and angular distortion), heterogeneity of chemical composition, microstructure and mechanical properties of weldment constituents, including mis-match effect, welding procedure, consumables and regime (especially heat input), residual stresses and stress relieving, service condition (aggressive environment, corrosion, stress-corrosion, low-cycle fatigue, low temperature) [2]. Full-scale cracked pressure vessel tests can provide an answer for simultaneous effect of many factors, but they are expensive. This explains growing interest for crack behaviour analysis based on tests of small notched (Charpy) or cracked specimens (fracture mechanics). However, the application of small specimen test results

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for full-scale pressure vessel (PV) crack analysis is possible only if stress and strain fields in crack region are similar. Tensile panel (TP) with surface crack can serve as a transition from small sized specimens to real structures. The comparison of results, obtained by tensile panels and real structures tests, can help for better understanding of crack behaviour and introduction of small specimen tests in the analysis.

EXPERIMENT

Pressure vessel and tensile panels were welded of yugoslav HSLA steel ČRN 460 (produced by Steelworks Skopje) of 460 MPa yield strength and 630 MPa tensile strength by submerged-arc-welding with overmatched weld metal. Stress relieving had been performed by heat treatment at 580°C for two hours.

Following experimental analysis is based on J integral direct evaluation method, developed by Read [3], and its application to full-scale pressure vessel for crack driving force measurement, Sedmak, Petrovski and Adžiev [4,5]. In order to simulate the real critical situation as close as possible, the crack tip was positioned axially in HAZ, in both TP (Fig. 1) and PV, [5]. The instrumentation consisted of 31 strain gauges, positioned along J integral path, properly selected around crack tip. Crack mouth opening displacement (CMOD) had been followed by clip gauge. Elastic compliance method based on CMOD measurement was applied in the experiment enabling an evaluation of crack extension during stable crack growth.

Results and analysis. Uniaxial elastic stress σ_u was used as a comparative measure in result analysis. For TP it was expressed as product of strain in remote points (Z10; Z20; ZV1; ZV11), and Young modulus, E = 210 GPa. The crack tip singularity effect can be neglected in remote points, as well as mis-match effect of WM. Equivalent stress in pressure vessel for plane stress condition is

$$\sigma = \sqrt{\sigma_t^2 - \sigma_t \sigma_a + \sigma_a^2} \tag{1}$$

where $\sigma_t = pD/2S$, $\sigma_a = pD/4S$, are hoop and axial stresses, respectively, p (MPa) is acting pressure, D = 1160 mm inner radius and S = 20 mm wall thickness.

It is clear that yield strains ($\varepsilon_Y = \sigma_Y/E \geq 2190\cdot10^{-6}$) were achieved in pos. Z7-8, Z17-18, ZV4-8 in pressure vessel, whereas general yielding occurred on uncracked side of TP (with largest strain in pos. ZV7) and only limited yielding in pos. Z7 on cracked side, but for the higher nominal stress level, as shown in Fig. 2. Higher compressive strains near crack sides in PV is a consequence of higher plastic strains in pos. Z7-8 and Z17-18.

Regular shape of J integral dependence is typical for both TP and PV (Fig. 3). J integral dependence on ε_{ud} is linear in both cases in elastic region, but with higher value for TP, what could be explained by constraints in PV, primarily due to observed angular distortion. Significant increase in J integral, started at $\varepsilon_{ud} = 1500 \cdot 10^{-6}$ in PV and $1900 \cdot 10^{-6}$ in TP, corresponded to small change of the remote strain, since net section yielding dominated and further load produced only the increase of crack opening. J integral curves for PV and TP are very close to each other when related to average strain ε_{pr}, expressed by the integrated area under strain in Fig. 2.

Surface crack reduces tensile strength and elongation (this is more expressed in PV), but there is still significant resistance to unstable crack growth, so that leakage before break can be expected for the tested PV. However, the results obtained by TP can be used for the safety analysis of PV due to similar shapes of J integral curves in both cases.

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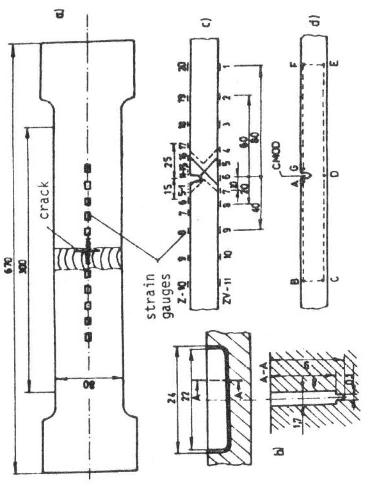

Fig. 1 Cracked tensile panel with the instrumentation

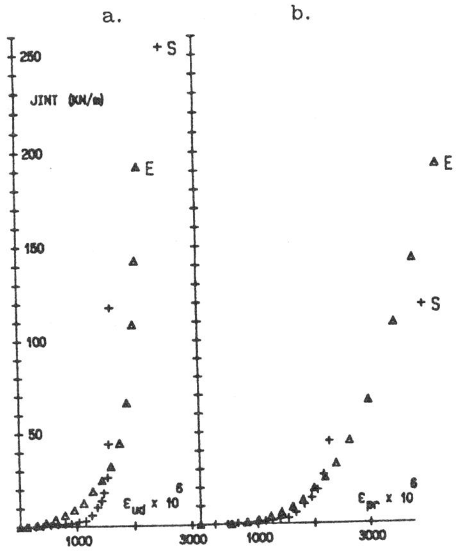

Fig. 3 J vs ε_{ud} and ε_{pr} for PV (S) and TP(E)

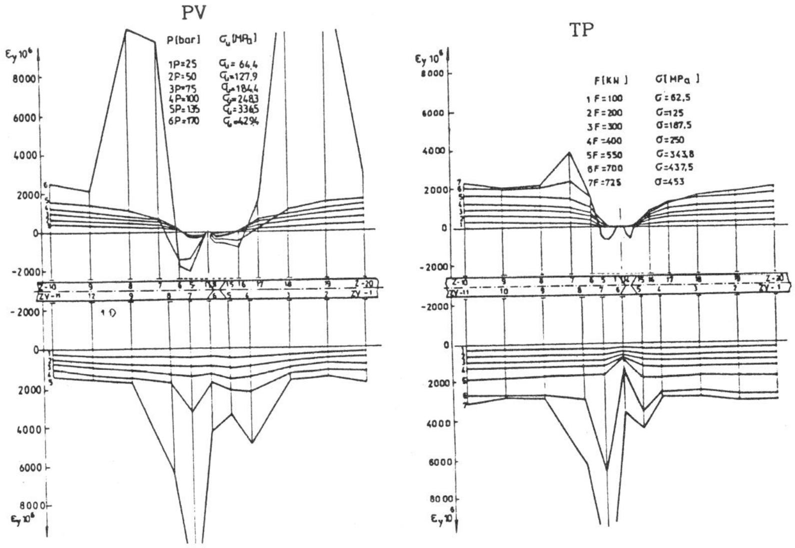

Fig. 2 Strain distribution around the crack in PV and TP