FRACTURE ANALYSIS OF A CrMoV STEEL WELDMENT UNDER DYNAMIC LOADING CONDITIONS

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The influence of the orientation of the fatigue precrack front and the weldment zones on dynamic fracture toughness, K_{Id}, has been investigated utilizing instrumented impact test equipment. A composite weld joint with crack front sampling all three zones of the weldment simultaneously was found to be an appropriate orientation for conservative fracture mechanics analysis in comparison to a cross weld joint orientation. The difference in crack tolerance capacity in two orientations is suitably illustrated.

INTRODUCTION

Weldment integrity through dynamic fracture toughness evaluation has received considerable attention in recent years, Logsdon and Begley (1), Logsdon (2), Hahn and Kanninen (3). Dynamic fracture toughness evaluation by means of testing pre-cracked Charpy impact specimens on an instrumented impact test machine is found to be a convenient and economic method because of the advantage of using small and compact specimens. Much of the effort has been expended on the characterization of weld metal and HAZ individually. In general for low alloy steels HAZ is found to possess the lowest toughness, Logsdon (4). For structural integrity assessment or for defect acceptance analysis, consideration of an appropriate value of fracture toughness is critical. In a quest to know this appropriate toughness it is necessary to find; (i) the effect of orientation of the propagating crack tip with respect to weld zone boundaries, and (ii) the effect of testing a composite of three dissimilar structures on the dynamic fracture behaviour in a component. Thus, the present investigation aimed at examining these two aspects for a low alloy CrMoV cast steel weldment through dynamic fracture toughness characterization.

MATERIAL AND EXPERIMENTAL PROCEDURE

The stress relieved weldment of a low alloy CrMoV cast steel investigated had the chemical composition given in Table 1. The welding was carried out utilizing manual metal-arc welding technique. The process parameters employed in welding

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are given in Table 2. Microstructural analysis showed an upper bainitic structure with localised lath type ferrites for the base material (Fig.1), a tempered bainitic structure for the weld metal (Fig.2), and tempered martensitic structure for HAZ (Fig.3). Weld joint Charpy V-notch impact samples were prepared in two mutually perpendicular directions, comprising all the three weld zones in the notch plane. In cross-weld joint samples crack initiation took place in one zone (weld metal in the present investigation) followed by further propagation through the HAZ to the third zone (base metal in the present studies). On the other hand, in the composite weld joint the pre-crack front sampled all the three zones simultaneously. The schematic illustration for the weld joint specimen preparation is shown in Fig.4. Samples precracked in a precracker unit to a crack-depth ratio of 0.35 approximately, were tested in an instrumented impact test equipment. Generated load-time and energy-time traces on the storage type oscilloscope screen were photographed on a polaroid film. A few of the broken samples were examined using the scanning electron microscope to analyse the fracture mechanisms.

TABLE 1: Chemical composition of weld keel-block investigated (weight %)

Element	C	S	P	Si	Mn	Cr	Mo	V	Al
Base material	0.16	0.013	0.014	0.35	0.75	1.05	0.90	0.23	<0.01
Weld deposit	0.06	0.011	0.017	0.25	0.63	2.40	1.00	--	<0.01

TABLE 2: Manual Metal Arc Welding Parameters

Electrode Type	E 90 15 B 3L		
Electrode Diameter (mm)	3.15	4.00	5.00
Arc voltage (volts)	20	25	25
Current (Amps)	120	180	200
Number of passes	16	140	64
Pre heat temperature (°C)	300 - 350		
Interpass temperature (°C)	Approximately 350		
Post weld treatment	680°C for 6 Hours		
Inspection after fabrication	Ultrasonic		

RESULTS AND DISCUSSION

Representative oscilloscope profiles and the corresponding fractographs for cross-weld joint tests are shown in Figs.5 and 6. The particular specimen under discussion has been precracked to a crack-depth ratio of 0.37. Crack initiation was found to have taken place in weld metal and further propagation occurred through the HAZ to base metal. Fractographic analysis along the precrack front in weld metal revealed dimples, Fig.7. Slightly away from the precrack front cleavage feature was observed in the HAZ, Fig.8. Further away from the precrack front, dimples were noticed in the base material, Fig.9. The dynamic fracture toughness for this orientation was evaluated using Linear Elastic Fracture Mechanics (LEFM) principles, Koppenaal (5) and found to be around 70.6 MPa $\sqrt{m}$. This value seems to be close to the weld metal toughness, 63.5 MPa $\sqrt{m}$, determined in an earlier work, Rajanna and Bhambri (6) wherein base metal, weld metal, and the HAZ were characterized for dynamic fracture toughness. In this study the K_{Id} values for base metal, HAZ and weld metal were found to be 93.6, 46.8, and 63.5 MPa $\sqrt{m}$, respectively. Thus HAZ has no significant control on the dynamic fracture toughness for this configuration.

The oscilloscope profile and corresponding fractographs for a composite weld joint specimen precracked to 0.34 crack-depth ratio are shown in Figs.10 and 11. In this configuration the precrack front has sampled simultaneously all the zones. Fracture morphologies in different zones along the precrack front are shown in Fig.12. These show a cleavage in the HAZ, cleavage and dimples in the weld metal and dimples in the base metal. A little further away from the precrack front the fractographic features are shown in Fig.13. These show dimples in the base metal, cleavage and dimples in the weld metal and cleavage in the HAZ. Dynamic fracture toughness in this case also has been evaluated using LEFM principles and found to be 42.7 MPa $\sqrt{m}$, which is very close but lower than the HAZ toughness 46.8 MPa $\sqrt{m}$ (6). Thus, dynamic fracture toughness of composite weld joint appears to be controlled by the HAZ. The observed cleavage features in the HAZ and dimples in the base and weld metals clearly indicate that crack initiation has occurred in the HAZ in preference to the base and weld metal.

The composite weld joint configuration results in a lower toughness, (by about 40%) compared to the cross-weld joint toughness. In the cross-weld joint, the toughness of the material in which crack initiation took place, was the controlling factor while in composite weld joint it was the HAZ that controlled the fracture toughness.

Tolerable Crack Size Predictions

For different crack geometries, the permissible crack sizes in a structural member can be predicted for a given design stress. In the present studies, a through thickness crack of length '2a' was assumed and the size was predicted for different weld zones employing the relation, Rolfe and Barsom (7)

$$K_{Id} = \sigma\sqrt{\pi a}$$

where K_{Id} is the dynamic fracture toughness of the particular zone and σ is the assumed design stress.

A superheated steam at a temperature of 565° and pressure of 15.9 MPa will be entering the turbine casing assembly. This in turn results in an internal pressure (hoop stress), σ_P, of the order 40 MPa alongwith an axial pressure, σ_a, of 20 MPa. In addition, the welding technique employed introduces a residual stress, σ_R, which is usually considered to be around 60 MPa for stress relieved welds prior to entering service (8). Thus the CrMoV weldment of the turbine casing, under consideration, is supposed to withstand a pressure of 120 MPa, the arithematic sum of σ_P, σ_a and σ_R. This particular stress has been considered as the design stress for crack length predictions. The analysis has shown crack lengths of 220.3×10^{-3} m and 80.54×10^{-3} m are tolerable in cross weld joint and composite weld joint configurations, respectively. Hence, the tolerable defect size is found to be considerably lower, by about 63.4%, in composite weld joint than the cross-weld joint configuration.

CONCLUSIONS

1) The relative orientation of the precrack front with respect to the weldment zones was found to influence the dynamic fracture toughness of the weld joint. The composite weld joint configuration had a much lower dynamic fracture toughness (42.7 MPa $\sqrt{m}$) in comparison to the cross-weld joint configuration (70.6 MPa $\sqrt{m}$).

2) Fractographic examination of the composite weld joint specimens has revealed that crack extension first-occurred in the HAZ in preference to base and weld metals which thereby controlled the dynamic fracture toughness of this configuration.

3) Critical crack size analysis for a through thickness geometry indicated a lower value, by about 63.4%, for composite weld joint in comparison to cross weld joint configuration.

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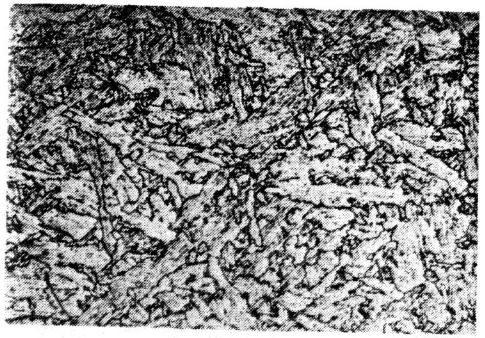


Fig.1: Upper bainitic structure for base material - Nital etch Magnification: 250X

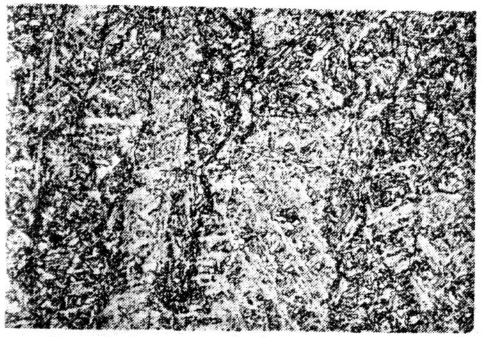


Fig.2: Tempered bainitic structure for weld metal - Nital etch Magnification: 100X

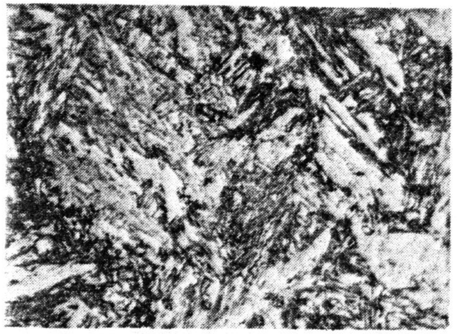


Fig.3: Tempered martensitic structure for heat-affected-zone - Nital etch Magnification: 250X

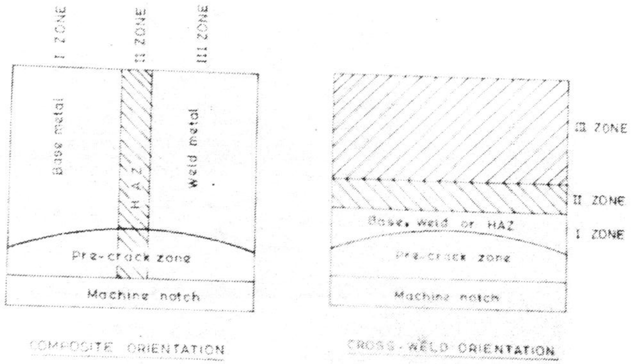


Fig.4: Schematic illustration for the weld joint sample preparation

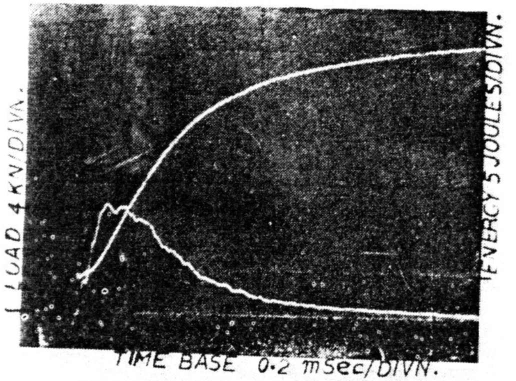


Fig.5: Representative oscilloscope profile for cross-weld joint samples

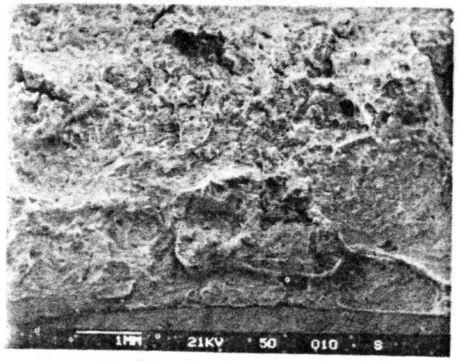


Fig.6: SEM Fractograph for the cross-weld joint sample

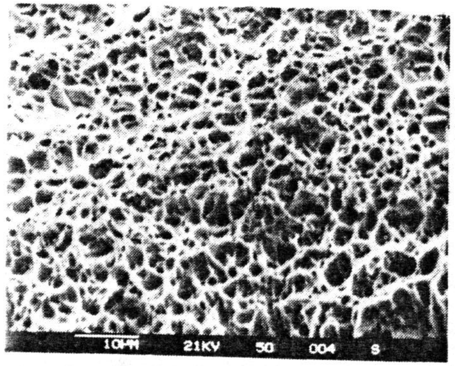


Fig.7: Fracture mode in weld metal of cross-wel
joint sample

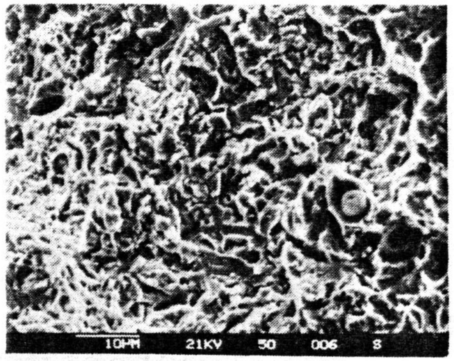


Fig.8: Fracture mode in HAZ of cross-weld joint
sample

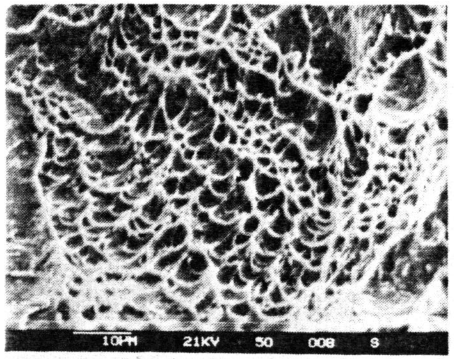


Fig.9: Fracture mode in base material of cross-w
joint sample

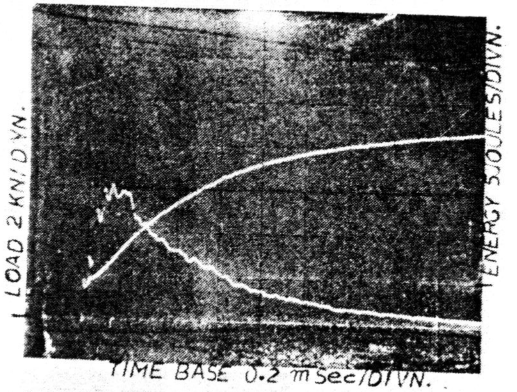


Fig.10: Representative oscilloscope profile
for composite weld joint sample

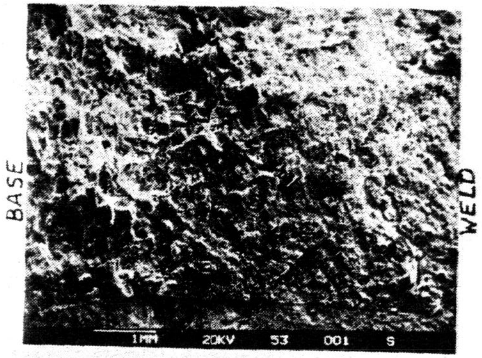
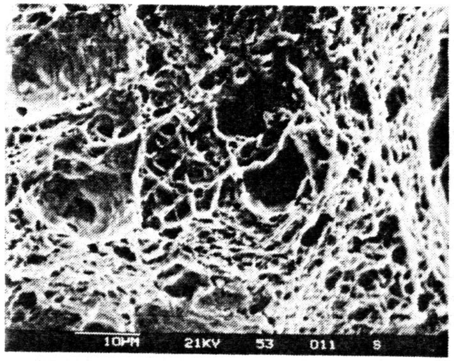


Fig.11: SEM Fractograph for the composite weld
joint sample



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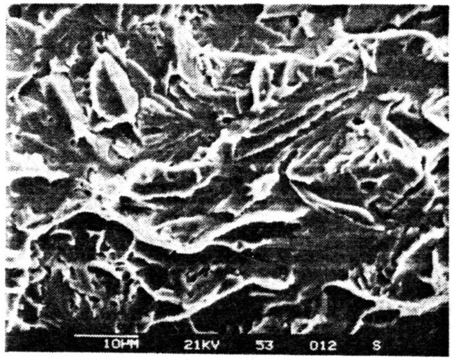

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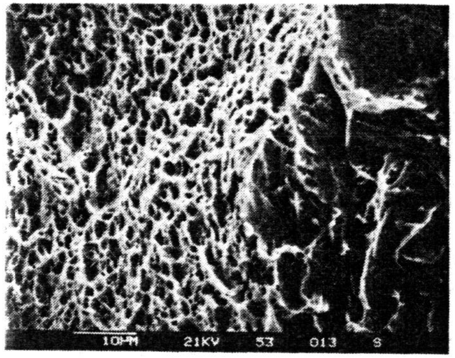
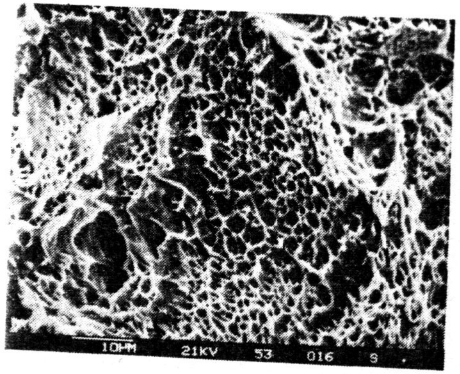


WELD

Fig.12: Fracture modes in different zones of composite weld joint sample : Near pre-crack front



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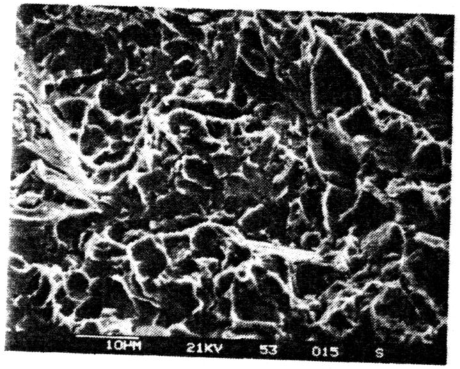
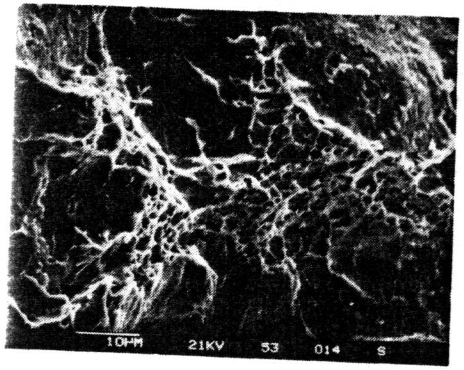


HAZ



WELD

Fig.13: Fracture modes in different zones of composite weld joint sample : Away from pre-crack front