CRACK BEHAVIOUR ANALYSIS IN THE HEAT AFFECTED ZONE OF MICROALLOYED STEELS

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Crack resistance of heat-affected-zone of three differently microalloyed steels has been experimentally studied, using specimens from simulated samples and welded joints. Normalized steel with 0.2% C exhibited brittle behaviour in some simulated samples, but behaviour of HAZ in welded joint is ductile. Thermomechanicaly control rolled steel, with low carbon content, are characterized by ductile behaviour of simulated samples, that is also the case of HAZ in welded joint. In some cases pop-in behaviour was observed for samples simulated at 1350°C, but in welded joint HAZ this was not observed, probably due to beneficial effect of subsequent run in multipass welding.

INTRODUCTION

Welded joint crack resistance, as a local material parameter, is depended on heat-affected-zone (HAZ) microstructure and mechanical properties of crack tip region. In the heterogeneous microstructure local brittle zones (LBZ) and local soft zones (LSZ) in HAZ govern crack behaviour of HAZ and welded joint, Fairchild (1). Crack resistance properties are described in most convenient way by fracture mechanics parameter, e.g. crack tip opening displacement (CTOD), Thaulow et al (2), Harrison (3). Simulation of HAZ region can help to understand better crack behaviour, enabling the evaluation of mechanical local properties of typical HAZ regions. The difference in crack resistance between simulated and welded joint HAZ sample, with crack tip positioned in same temperature region, can be significant due to effect of surrounding material in a welded joint. Comparative study of simulated and welded joint samples is necessary for better evaluation of crack resistance .

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MATERIALS AND TESTING

Three different steels of the same thickness (13 mm) has been selected for experimental analysis of crack behaviour in HAZ: vanadium microalloyed steel, normalized with special cooling, and two thermomechanicaly control rolled steels, microalloyed with V+Nb and Ti+Nb. Steels chemical composition is given in Table 1, and mechanical properties listed in Table 2. Crack behaviour has been studied by the analysis of CTOD on precracked Charpy size specimens, produced from simulated and welded joint samples, with the crack tip positioned in (HAZ) at different distances from fusion line. Specimens fracture surface was studied by SEM. Simulated samples had been produced on SMITHWELD simulator at 1350°C (coarse grains formation), at 1100°C (fine grains region), at 950°C (fine grains region above A_3 temperature) and at 850°C (temperature between A_1 and A_3, intercritically heated region). Cooling rate $\Delta t_{8/5}$ was adjusted by 15 sec as holding time.

TABLE 1 - Steel chemical composition

Steel	C	Si	Mn	P	S	Al	Cu	Nb	Cr	Ni	Mo	Ti	V
A	0.20	0.51	1.42	0.020	0.010	0.018	0.035		0.018	0.574	0.017		0.180
B	0.07	0.43	1.43	0.012	0.012	0.037	0.043	0.031	0.018		0.017		0.087
C	0.08	0.20	1.12	0.027	0.011	0.033	0.065	0.026	0.065	0.019	0.010	0.017	

TABLE 2 - Mechanical properties of tested steels

Steel	Yield strength, MPa	Tensile strength, MPa	Elongation, %	Impact toughness, J	Hardness, HV_5
A	490	720	17.0	130.2	262
B	460	596	32.7	142.7	204
C	430	520	34.6	228.9	199

Welded joint samples of three steels were prepared by manual metal arc multipass welding, using Thyssen SH W 1 coated basic electrode. Fatigue crack tip in Charpy size specimens was positioned in different regions of welded joint HAZ.

TESTING RESULTS

The results of simulated samples CTOD testing are listed in Table 3. From obtained load vs crack mouth opening displacement (CMOD) it is possible to calculate CTOD values, using procedure and formulae from BS 5762. For steel A specimens 1 and 2 (Table 3) CTOD values correspond to complete brittle behaviour and valid results for plane strain fracture toughness K_{Ic} according to BS 5447 are obtained (1890 $N/mm^{3/2}$ and 1498 $N/mm^{3/2}$, respectively). Typical diagram for this case is given in Fig. 1, and corresponding fracture surface, exhibiting cleavage fracture, is presented in Fig. 2. The diagram for steel B specimen 1, given in Fig. 3, presents a pop-in behaviour, because the specimen fractured after some plastic deformation. On the fracture surface (Fig. 4) portions of cleavage and ductile fracture could be recognized. Specimen 1 of steel C exhibited also a kind of pop-in (Fig. 5), because it fractured after significant plastic deformation, but before maximum load is reached. Fully ductile behaviour, with maximum load level reached, is typical for all the other specimens of all three steels.

TABLE 3 - Crack tip opening displacement of simulated samples

	Specimen number and simulation temperature			
Steel	1 - 1350°C	2 - 1100°C	3 - 950°C	4 - 850°C
A	0.007	0.008	0.164	0.130
B	0.178	0.260	0.536	0.510
C	0.349	0.641	0.695	0.754

Comparison of different HAZ regions and simulated specimens is possible under condition that fatigue crack tip is positioned in corresponing HAZ microstructures. The requirement was to locate crack tip in specimens at the same distance from fusion line in welded joint HAZ, close to corresponding simulation temperature (Fig. 6). It can be seen from Table 4 that this requirement is not fulfilled completely.

Ductile behaviour was observed for the welded joint HAZ specimens of all three steels, and obtained CTOD values, which are significantly higher compared to simulated samples, correspond to maximum load level and indicate some improvement of HAZ ductility, that is clearly expressed in the case of steel A.

TABLE 4 - Crack tip opening displacement for welded joint HAZ samples

	Distance from fusion line, mm										
Steel	4.5	4	3.1	2.6	2.3	2.0	1	0.8	0.4	0.32	0
A		0.32			0.38			0.20			0.32
B	0.56			0.42			0.45		0.39	0.41	0.21
C	0.61	0.41		0.49		0.30					0.20

ANALYSIS AND CONCLUSION

Simulated samples of tested three microalloyed steels indicated different behaviour. Brittle behaviour of normalized steel with 0.2% C can be attributed to inconvenient microstuctural changes during heating. It is interesting that simulated samples of thermomechanicaly control rolled steels, behave differently: when microalloyed with V+Nb at some temperature pop-in occurred, although C content is low (0.08%), and complete ductile behaviour for all simulation temperature is typical for Ti+Nb microalloyed steel. This behaviour is in accordance with previously obtained results for instrumented impact tests and analyzed fracture surfaces, Gerić (4). From these tests one can conclude that steel A is critical for welding due to degradation rate of material in HAZ, caused by inconvenient changes of microstructure and toughness. Steel B can be evaluated as weldable, but some precaution must be taken because of possible local pop-in behaviour in HAZ. Impact toughness level for this steel is acceptable, but cracked specimens testing revealed local brittle behaviour of microstructure in the vicinity of fusion line (Fig. 4). The sensitiviy of cracked specimens testing compared to notched impact toughness testing is confirmed with this result. It is confirmed with this result generally accepted Steel C is also suitable for welding; but again brittle behaviour in the region close to fusion line could be expected. Some reduction in strength, indicating the presence of local soft zones, can be neglecting in this case.

Behaviour of welded joint samples of tested steels is not in accordance completely with the behaviour of simulated samples. Improvement in behaviour is observed for A steel samples, that means expected detrimental effect of welding, based on simulated samples properties is not expressed in HAZ of welded joint. With properly selected welding regime parameters acceptable welded joint quality level could be achieved.

In the case of both steel B and C behaviour of welded joint samples is inferior compared to simulated samples. The explanation of such a behaviour requires further experimental analysis.

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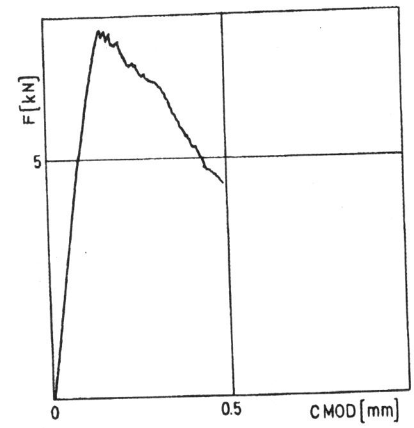

Figure 1 Typical brittle behaviour of steel A specimen 1

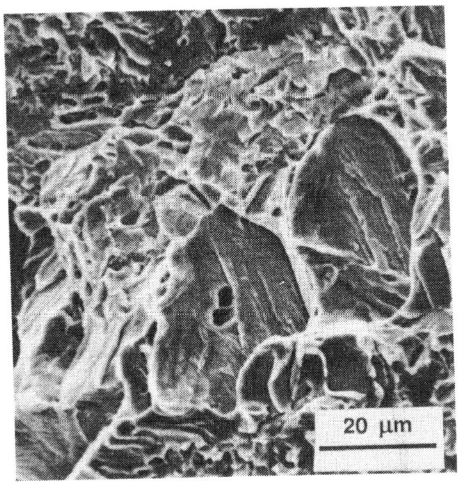

Figure 2 Cleavage fracture surface of steel A specimen 1

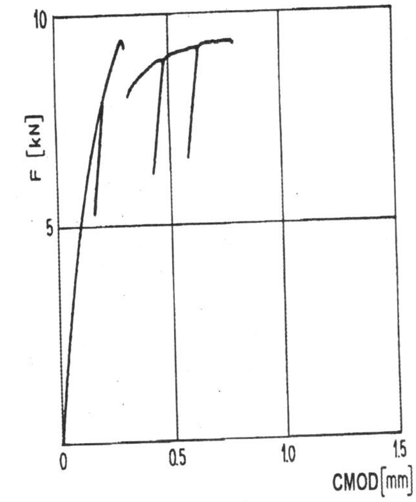

Figure 3 Load vs CMOD for steel B specimen 1, with pop-in behaviour

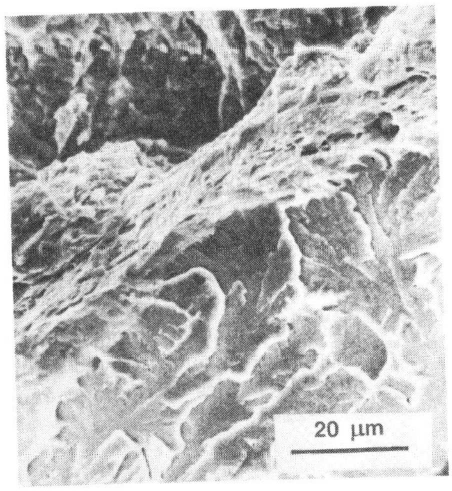

Figure 4 Fracture surface of steel B specimen 1

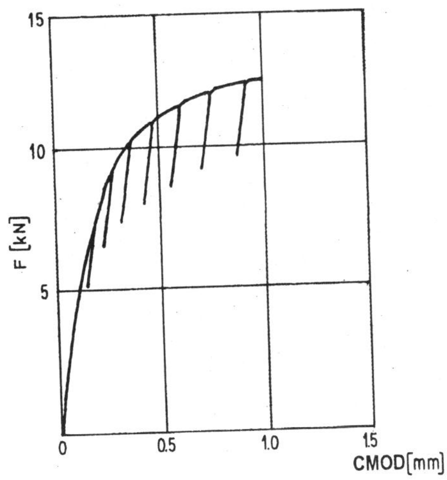

Figure 5 Load vs CMOD for steel C specimen 1

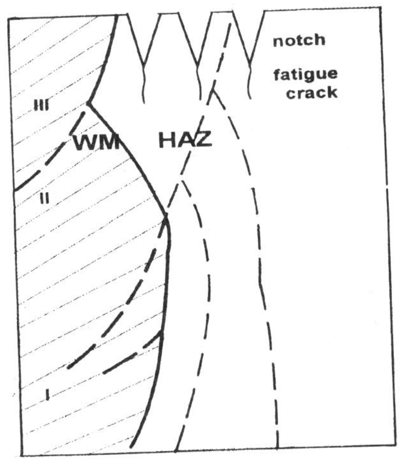

Figure 6 Position of crack tip in different HAZ region