THE EVALUATION OF BRITTLE FRACTURE BEHAVIOUR OF HIGH STRENGTH STEELS WELDMENTS

A. Radović*, S. Sedmak**, V. Grabulov* and B. Veljanovski*

Three different testing methods (instrumented impact, explosion crack starter and fracture mechanics tests) had been applied for brittle fracture behaviour evaluation of two kinds of welded joints, produced of high strength steels by manual arc welding. The results, obtained for BM, WM and HAZ are analyzed and compared. It was concluded that applied testing methods do not exclude each other, since they produce complementary results, helping to understand better brittle fracture behaviour of welded joints heterogeneous structure.

INTRODUCTION

The application of high strength steels for welded constructions is dependent on the properties of their welded joints. One of the most important requirements for service safety of welded structures, produced of high strength steel, is to achieve corresponding level of toughness in all three weldment constituents : base metal (BM), weld metal (WM) and heat-affected-zone (HAZ). The evaluation of weldments toughness is very complex, because of microstructures heterogeneity of WM and HAZ, as well as the heterogeneity of their mechanical properties. Charpy test, although very old method, is generally accepted for the evaluation of the impact toughness due to its simplicity. Recently developed instrumentation of Charpy test significantly extended its capacity (1), enabling not only the separation of energy portions required for crack initiation and crack propagation, but also the evaluation of loading during the fracture process. Specifications for heavy loaded welded structures normally include impact energy values for BM and WM, as well as transition temperature when service at low temperature is expected. However, there is still the problem how to evaluate toughness of HAZ, since it is difficult to position notch root precisely in HAZ region of lowest toughness.

In order to establish more severe testing loading, explosion crack starter test had been introduced (2). Fast loading rate and notched brittle bead, welded on the plate specimen assured severe testing conditions. Applied to welded joint specimens (3), this test enables to determine the most critical region in weldment, in which fracture would occur. In this way by the global test critical local property could be defined.

Further improvement in crack resistance testing is offered by introduction of fracture mechanics tests, that involved pre-cracked

*Military Technical Institute, Belgrade, Yugoslavia
**Faculty of Technology and Metallurgy, Belgrade, Yugoslavia

specimens. The application to welded joints allows for convenient determination of crack resistance of BM and WM, but it is followed again by uncertainty in defining of critical crack tip position in HAZ (4), since in prescribed preparing method fatigue crack would follow the path of notch root rather than direction of critical HAZ region.

The application of all three above described methods for the evaluation of brittle behaviour of welded joints, performed of high strength steels by manual arc welding, are presented in the paper.

BASIC PROPERTIES OF TESTED WELDED JOINTS

Parent Steels

Two kinds of high strength steels were used in these tests: NN70, Yugoslav product of HY100 type steel, d = 18 mm thick, designed in next text as "A", and Č.5432 according to Yugoslav Standards (JUS), Q&T Cr-Ni-Mo steel of 1000 MPa nominal ultimate tensile strength, d = 20 mm thick, designed as "B" in next text. Their typical heat analysis and tensile properties are given in Table 1.

Table 1. Heat analysis and tensile properties of tested steels

Steel	Chemical composition									
	C	Si	Mn	P	S	Cr	Ni	Mo	V	Al
"A"	0.1	0.27	0.35	0.014	0.012	1.11	2.65	0.26	0.1	0.05
"B"	0.3	0.28	0.73	0.02	0.008	2.05	1.87	0.3		

Steel	Mechanical properties			
	Yield strength Y.S. MPa	Ultimate tensile strength U.T.S. MPa	Elongation A %	Reduction of cross-section area Z %
"A"	780	825	18	68
"B"	940	1015	16.7	58.2

Electrodes

Welding of steel "A" had been performed using Tenacito 80 covered basic electrode. Chemical composition of Tenacito 80 is (%):
C: 0.06 Si: 0.50 Mn: 1.80 Cr: 0.35 Ni: 2.20 Mo: 0.40
Yield strength of all weld metal Tenacito 80 is above 750 MPa, its ultimate tensile strength 810 to 910 MPa, and elongation > 16 %.
Welding of steel "B" had been performed using an austenitic basic electrode 18/10/7Ti with chemical composition (%): C:0.1 Si:0.3-0.7 Mn: 5-7 P: 0.035 S: 0.013 Cr: 19-22 Ni: 9.5-10.5 Ti: 0.2-0.5.
Yield strength of all weld metal is 380-580 MPa, ultimate tensile strength 550-700 MPa, elongation > 22%.

Welded Joints

Welding direction was transverse to steel rolling direction. Deposit weld metal of steel "A" exhibited Y.S. of 747 MPa, U.T.S. - 785 MPa and elongation of 19.3%. For steel "B" welded joint, that fractured in specimen weld metal region, U.T.S. was 650 MPa. In the case of steel "B" defect free welded joint had been required and strength level was not specified for this application.

RESISTANCE TO BRITTLE FRACTURE

Brittle fracture resistance of steel "A" and its welded joints is evaluated by instrumented impact, explosion and fracture mechanics tests, performed for BM, WM and HAZ. Only instrumented impact and explosion tests were performed for steel "B" and its welded joint specimens, having in mind exaggerated undermatching effect.

Charpy V specimens were tested at different temperatures in the instrumented impact test. Parent plate specimens were cut in the rolling (L) and in transverse direction (C) with notches normal to these directions. The notches in weldment specimens were positioned in WM and in HAZ. Typical results are presented in Fig. 1.

Explosion crack starter test specimens (5,6) were 500x500xd mm. Brittle bead was welded in both directions on steel "A" plates, in (C) direction on steel "B" and in the direction of tested weldment, and the notch as crack starter was normal to the bead direction. Figure 2 presents scheme for explosion crack starter test, and test results are given in Fig. 3, expressed by bulge development B and thinning ΔR with explosions number. Typical development of crack in explosion tests is presented in Fig. 4 for welded joint specimens.

Fracture mechanics parameters were tested on SEN (B) specimens 14x28 mm cross-section for steel "A", its WM and HAZ, using single specimen J_{Ic} procedure. Critical crack-opening displacement δ_c for maximal load could also be determined in this test. The results of fracture mechanics tests are listed in Table 2.

Table 2.
Critical J integral J_{Ic} and critical crack-opening-displacement δ_c for BM steel "A", its weld metal (WM) and heat-affected zone (HAZ)

	BM			WM			HAZ		
Critical J integral J_{Ic}, kN/m	195	209	257	94	105		176	320	
Critical crack opening displacement, δ_c, μm	63	85	103	66	80	90	167	183	208

Welded joints hardness numbers are given in Fig. 5.

Nil-ductility-transition temperatures, determined for 50% upper shelf impact energy and from explosion test, are listed in Table 3.

Table 3 Nil-ductility-transition temperatures, °C

	Steel "A"				Steel "B"			
	(L)	(C)	WM	HAZ	(L)	(C)	WM	HAZ
50% Charpy V impact energy	-138	-100	-52	-94	-56	-62	-105	-48
Explosion test		-103	-85			-84	-130	

DISCUSSION

The obtained results can be considered from two stand-points. One of them is related to brittle fracture properties of welded joints constituents, the second is the comparison of three test methods.

Steel "A" impact toughness is satisfactory in both directions, and its behaviour at low temperatures is also satisfactory. Anyhow, this is not the case with its weld metal, because NDT temperature for impact energy of 27 J is only -25 °C, higher than the value for 50% upper shelf eneregy. Heat-affected-zone in this test was found to be superior compared to weld metal.

Having in mind high strength of steel "B", impact energy values can be accepted as satisfactory, including transition temperature. Higher impact values of WM compared to BM corresponds to high alloy consumable. The results for HAZ are comparable to BM results.

High quality of steel "A" welded joints is proved in explosion crack starter test. The cracks, emanated from brittle bead notch, are arrested in base metal (Fig. 4a) in most specimens, and in some cases fusion line of HAZ was critical welded joint region as regard brittle fracture (Fig. 4b). No significant difference was found comparing base metal and welded joint specimens, e.g. after sixth shot thinnings and bulge developments were comparable (Fig. 3a,b) for same explosive charge.

Extremely low reduction of thickness in explosion test of steel "B" (less than 4% after eight shots), followed by small bulging of only 40 mm is an evidence of brittle behaviour, better expressed than by impact test. In all tested welded joints specimens fracture was limited to weld metal (Fig. 4c), due to lower strength of WM.

Hardness values in Fig. 5 correspond to the expected levels for both (steel "A" and "B") welded joints, some scatter in WM of steel "A" can be attributed to multipass welding.

The results of fracture mechanics tests (Table 2) show that best crack resistance is typical for HAZ, and the lowest for WM. Since the precise position of crack tip in HAZ can not be defined, this behaviour can be considered as an average result. Comparing to impact test results, some disagreement can be found, since they have shown best resistance in BM, and not in HAZ. General view of fracture appearance, Fig. 4b, c, indicates that HAZ can be critical region, but this conclusion scarcely could be described by fracture mechanics test, or impact test.

REFERENCES

1 Instrumented Impact Testing, ASTMSTP 563, ASTM Philadelphia, 1974.
2 W.S.Pellini, Guidelines for fracture-safe and fatigue-reliable design of steel strustures, The Welding Institute, Abington, 1983.
3 Matthews,J.R., Porter,J.F., Church,J. and Macecek,M., Welding J. 36, 1991, pp 35-41.
4 S.Sedmak, Welded joint properties evaluation by cracked specimens testing, in Fracture Mechanics of Wedlments, Goša-TMF, Belgrade, 1985, pp 281-306.
5 Standard Procedures for Explosion Testing Ferrous and Non-Ferrous Metallic Materials and Weldments, MIL-STD-2149 (SH), November 1983.
6 Porte,J.F., Morehouse,D.O. nad Matthews,J.R., Response of SMA and Narrow Gap HY80 Weldments to Explosive Shock Loading, DREA Technical Memorandum 88/206, 1988.

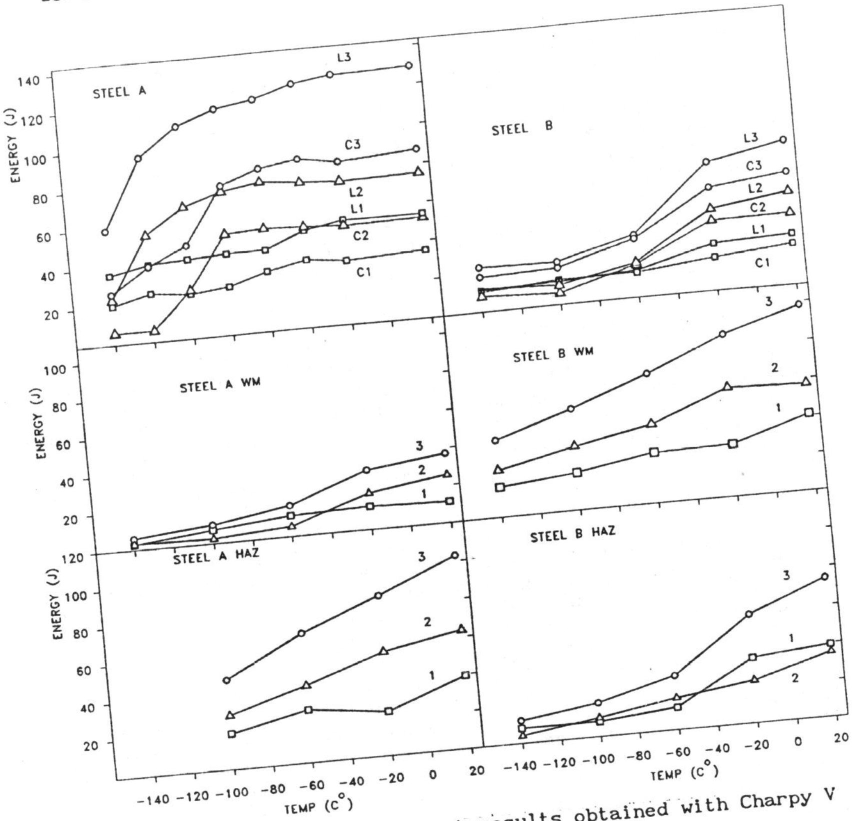

Figure 1 Instrumented impact test results obtained with Charpy V specimen
WM-weld metal
HAZ-heat-affected-zone
1 crack initiation energy 2 crack propagation energy
3 total energy
L-notch in cross-rolling direction
C-notch in rolling direction

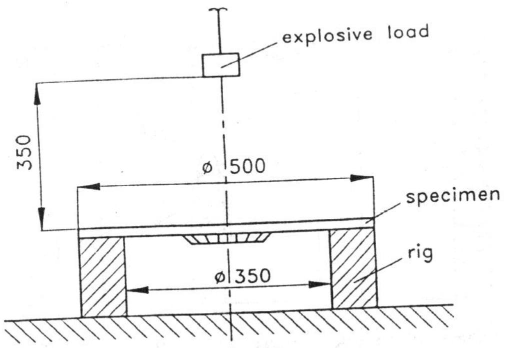

Figure 2 The scheme for explosion bulge test

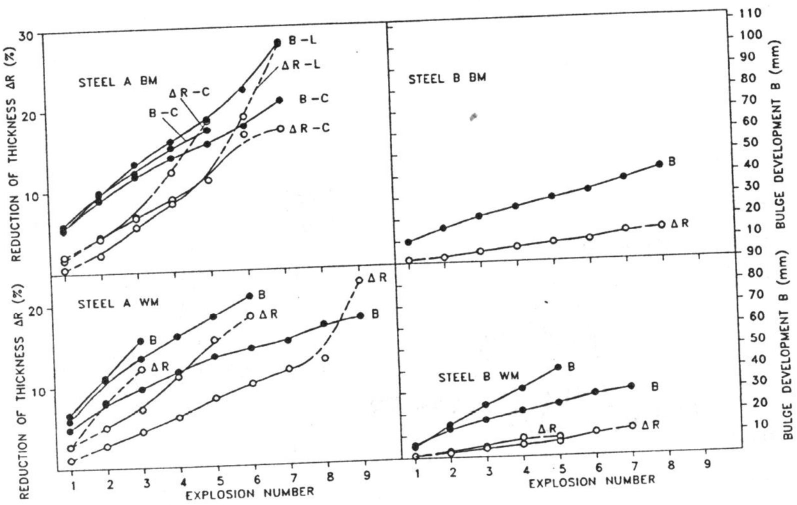

Figure 3 Typical results of explosion bulge test, expressed by reduction of thickness ΔR and bulge development B vs. number of explosions for indicated specimens
L-notch in cross-rolling direction
C-notch in rolling direction
WM-weld metal

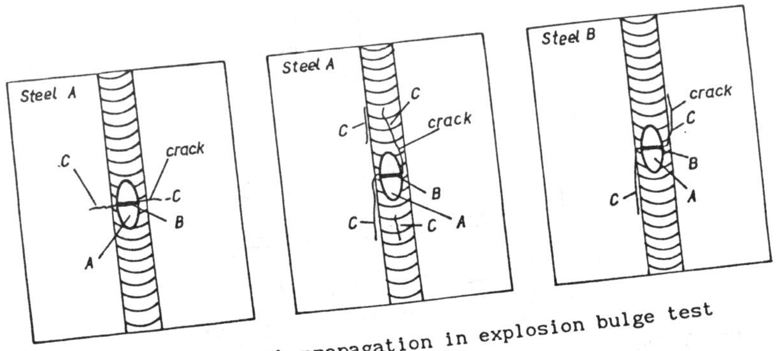

Figure 4 Scheme of crack propagation in explosion bulge test
A brittle bead
B notch-crack starter
C crack

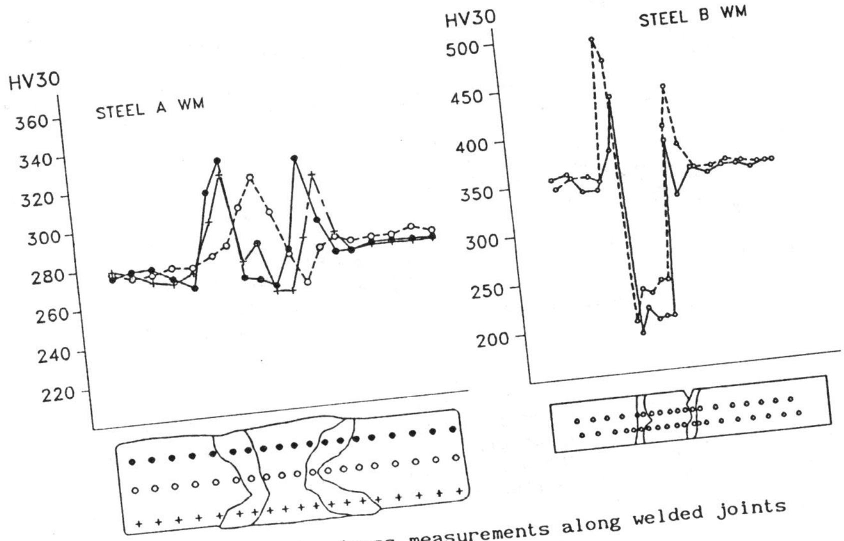

Figure 5 Results of hardness measurements along welded joints