THE SIGNIFICANCE OF NOTCH POSITION IN TESTING WELDED BEADS

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Summary

Charpy V-notch, static and dynamic TPB tests have been performed on specimens machined from multipass weld beads. The crack starter notches were positioned at the midsection of the bead, as well as 3 mm off the midsection. The results have shown that fracture characteristics are sensitive to the position of the notch and under circumstances may be superior in the midsection compared to other sections. However, to demonstrate this difference an adequate testing method must be selected.

Introduction

The accurate knowledge of the mechanical properties of welded joints and consequently their careful examination is of increasing interest since the requirements concerning welded structures are growing continuously. In the process of dimensioning a variety of mechanical parameters are used. Additionally one of the most important features, is fracture behaviour because of the possibility of catastrophic rupture, which may result through a failure of a single element of the structure due to a relatively small defect at a critical location.

To assure safety on one hand and to utilize at the same time the load bearing capacity to its possible maximum, raises the demand for reliable fracture tests.

In practice, the Charpy type impact test, as the most simple one, is generally used. This provides, as a final result, a transition temperature characteristic for the plastic—brittle transition of steels, based on empirical criteria. More sophisticated tests result in fracture mechanics parameters suitable for direct application in dimensioning. All fracture tests have the common feature that the specimen contains a crack starting stress raiser (notch

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or crack), which restricts the final fracture to a pre-selected cross section. The crack, however may deviate from this, but generally in such a case the test is not regarded as valid. Deviations of the crack path from the pre-selected cross section occur, if the material to be tested is very inhomogeneous.

Inhomogeneity is typical for welded beads, but this is not considered in every detail in fracture tests. Base metal, heat affected zones and weld metal are usually tested separately, but inhomogeneities within the weld metal are disregarded. In many cases the differences of local properties are not too big and therefore the crack path will not be influenced: fracture occurs at the preselected section. The measured data, however, may be misleading, if the tested section is not the "weakest link" in the joint and neighbouring material parts are inferior.

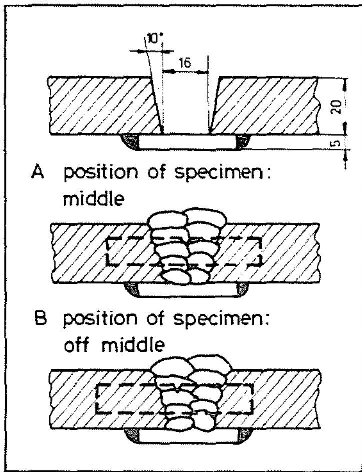
The aim of this work is to present the investigation on multipass weld metals with respect to local fracture properties to demonstrate the importance of the notch and crack position resp. and to examine the reliability of everyday practice: positioning the notch and crack resp, at the midsection of the weld beads.

The work has been performed as a joint research program of the Institute for Materials Science and Testing, the Institute of Testing and Research in Materials Technology (TVFA) of the Technical University Vienna and the Institute for Technology and Materials Science of the Technical University Budapest [1, 2].

Test material

On a 500 MPa type fine grain structural carbon steel, as base material, multipass butt welds have been prepared by CO_2 gas shielded welding procedure. Details of the welding process as well as the position of the individual layers are given in *Fig. 1.* A photograph of a cross section of a typical weld bead is shown in *Fig. 2.*

It is obvious that the microstructure of the bead is not homogeneous, coarse and fine grained areas are alternating. The coarse grains result from direct crystallization of the molten material, while the fine grain is a consequence of heat treating by subsequent passes. Since it was demonstrated by many previous experiments that the grain size has a strong influence on the fracture properties, it has been concluded that the ratio of areas with coarse or fine grains resp., in a given cross section could affect the results of fracture tests. Therefore the specimens were machined in two different ways off the beads positioning the notch and starting crack at the midsection (A) or off the middle (B) resp.—as illustrated in Fig. 1.



Welding parameters:

Welding wire VIH-2, 1.2 mm dia.
(0.10 % C, 0.93 % Si, 1.34 % Mn
0.015 % P, 0.018 % S, 0.18 % Cu)
Interpass temperature: 250 °C
Welding velocity: 300 mm/min
Gas consumption: 14 l/min
Mean welding voltage: 25 - 26 V
Mean welding current: 220 - 245 A
Base material, 0.20 % C, 0.42 % Si
1.36 % Mn, 0.030 % P, 0.042 % S

Fig. 1. MAG-welding: Preparation, position of specimens and welding parameters

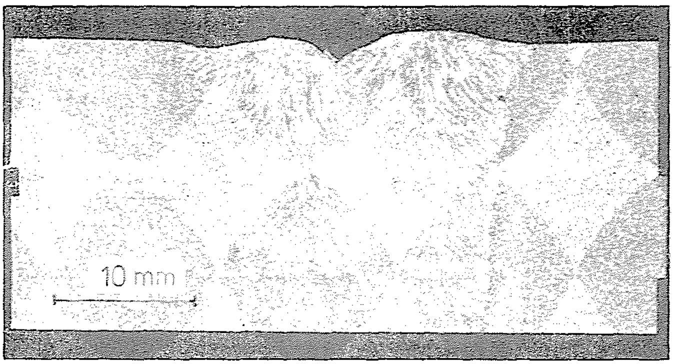


Fig. 2. Photograph of a weldment

Testing methods and equipment

ISO–V impact bend tests, static and dynamic three point bend (TPB) tests have been performed as a function of temperature on specimens of both types A and B. Dimensions and shape of the test pieces are shown in *Fig. 3.* Precracking of the specimens was accomplished by using an electromagnetic resonant machine at 200 cycles/sec and a special electronic device for automatic control, developed by the TVFA of TU Vienna. The amplitudes were held far below the limits given in ASTM E 399 or E 813. The crack front was relatively straight and the scatter of crack lengths low.

The specimens tested at other than room-temperature were cooled in a thermostat and held there for at least 15 minutes. Dynamic specimens were super-cooled with $\Delta T/20$ K, where ΔT is the difference of testing and room-temperature and the tests were performed within less than 8 sec after taking the specimens out of the thermostat. Static specimens were continually cooled during the test.

For the impact bend tests and the dynamic TPB tests a Schnadt type impact pendulum has been used, instrumented to record load/time and load/deflection diagrams [3, 4]. The impact bend tests have been performed with an impact velocity of 5 m/sec, while for the TPB tests the velocity has been reduced to 0.1 m/sec. Examples of the recorded load/deflection curves for the latter are given in *Fig. 4* [2].

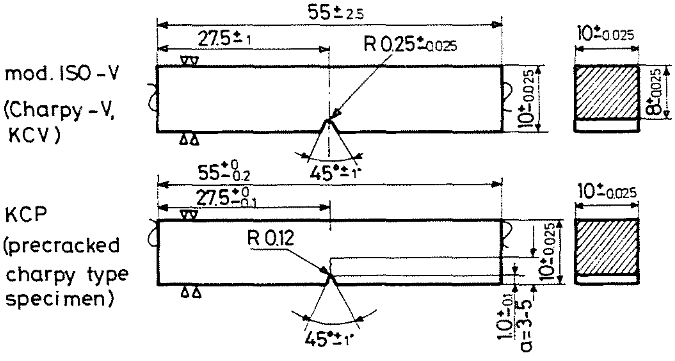


Fig. 3. ISO–V and precracked Charpy type impact specimens

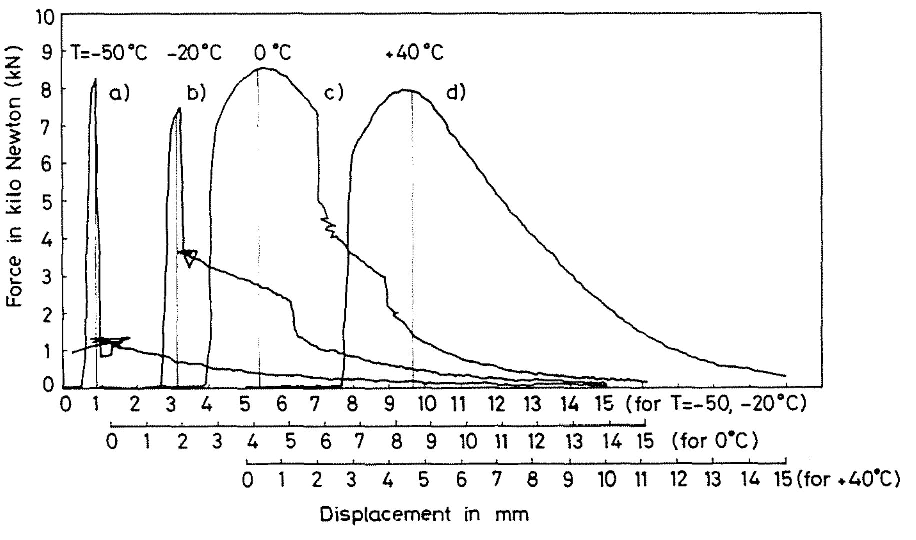


Fig. 4. Load displacement diagrams of precracked Charpy type specimens taken from MAG weldments [2]

The static tests have been made on an electromechanical tensile machine with a capacity of 100 kN. Clip-gage displacement as well as deflection were monitored during the tests as a function of load (*Fig. 5*). The cross head speed was 2 mm/min.

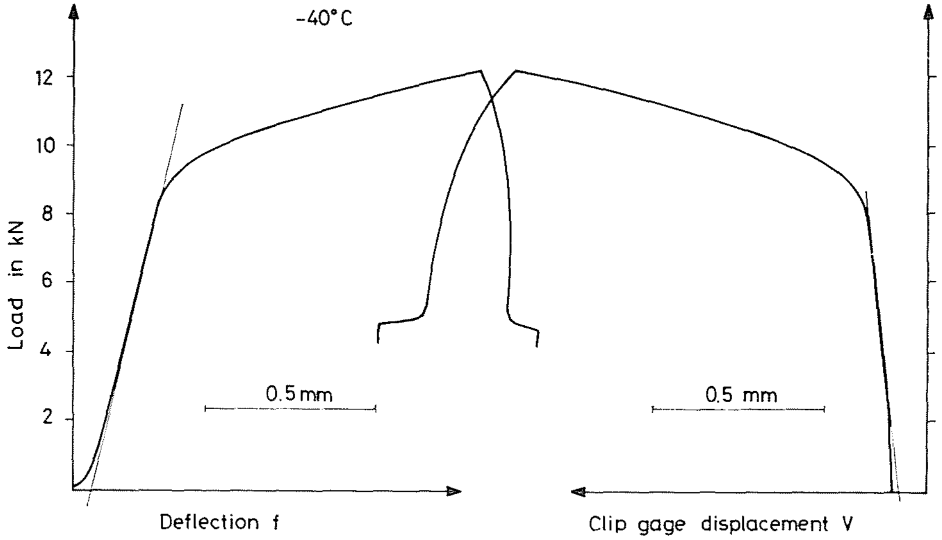


Fig. 5. Deflection and clip gage displacement as a function of load in a static TPB test

Test results and discussion

The results of ISO–V impact bend tests of both A and B positions are listed in *Tables 1 and 2* as a function of temperature. Except of A type specimens at +20 and +50 °C, 3–5 test pieces were used at each temperature. The average values of these are also given in the tables.

The results are also illustrated in *Fig. 6* [2], showing the average values and the scatter bands. It is obvious that the specimens of position A show higher absorbed energies compared to those of position B in the whole temperature range tested. However, the difference is relatively small and the scatter bands overlap each other.

A very similar conclusion can be made using fracture mechanics results on the basis of the static TPB tests. The individual results are given in *Table 3* and in *Figs. 7 and 8*. Though the difference caused by the different positions of crack planes is obvious, the scatter of the results may lead under circumstances to a wrong conclusion—namely, that the notch or crack position has no influence. It is worth-while to mention that the trend is just the same whether COD, or J-integral is used to interpret the fracture behaviour.

Table 1

Results of ISO-Charpy-V tests. Notch position: "A"

Sample	Testing temperature (°C)	KV values (single) (J)	KV values (average) (J)
4–13	+50	118	118
4–1	+20	101	98
2		94	
4–3		81	
4	0	85	80
5		67	
13		86	
4–6		69	
7	−20	77	68
8		60	
12		66	
4–9		45	
10	−40	39	38
11		29	

Table 2

Results of ISO-Charpy-V tests. Notch position: "B"

Sample	Testing temperature (°C)	KV values (single) (J)	KV values (average) (J)
3–12		112	
13	+50	102	105
14		100	
3–1		98	
2		62	
19	+20	115	95
20		105	
21		93	
3–3		93	
4		63	
5	0	82	76
15		74	
16		68	
3–6		54	
7		24	
8	−20	43	38
17		38	
18		33	
3–9		40	
10	−40	39	34
11		22	

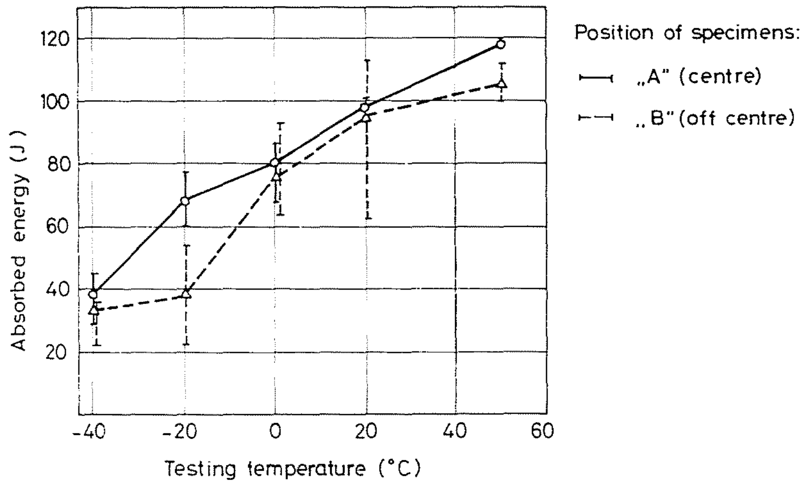


Fig. 6. Results of ISO-Charpy-V-tests [2]

Contrary to the former, dynamic TPB tests provided a very distinct difference between the two batches of specimens. The calculated J-integrals are given in *Fig. 9* [2]. The transition temperature is shifted by 30 K to a higher temperature by moving the crack plane of the specimens by about 3 mm off the middle.

Table 3

Fracture mechanics results of static TPB tests

Sample	Testing temperature (°C)	J (kJ/m²)	K_{IJ} (MPa m$^{1/2}$)	δ (mm)
B 1	0	498	320	0.476
B 2	0	467	310	0.491
B 3	−20	449	304	0.470
B 4	−20	444	302	0.542
B 5	−40	308	252	0.326
B 6	−40	156	179	0.179
A 11	0	609	354	0.558
A 12	0	542	334	0.538
A 14	−20	498	320	0.522
A 15	−40	262	232	0.297
A 16	−40	492	318	0.529

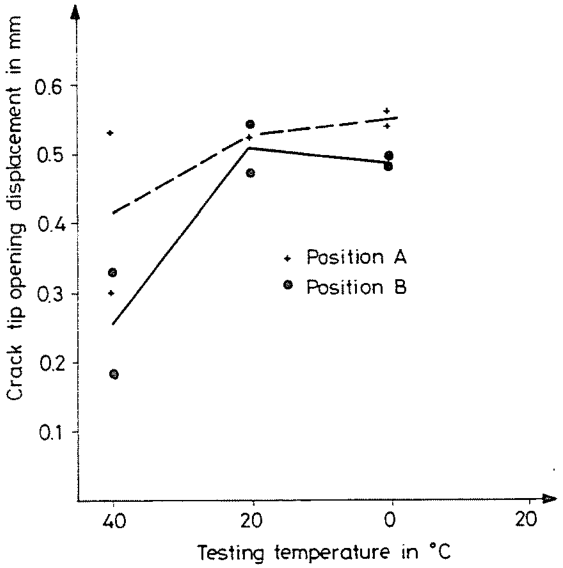


Fig. 7. CTOD values as a function of temperature

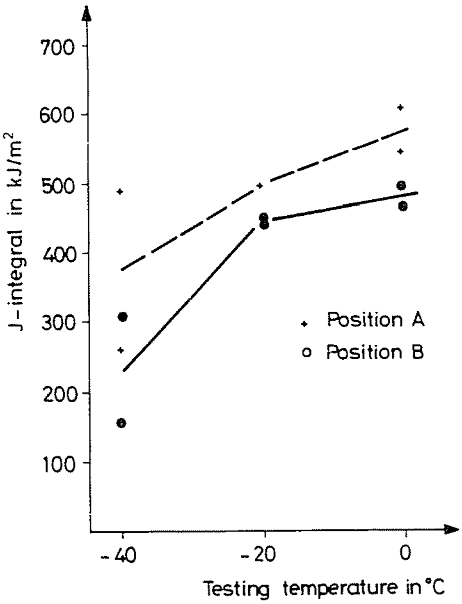


Fig. 8. J-integral values as a function of temperature

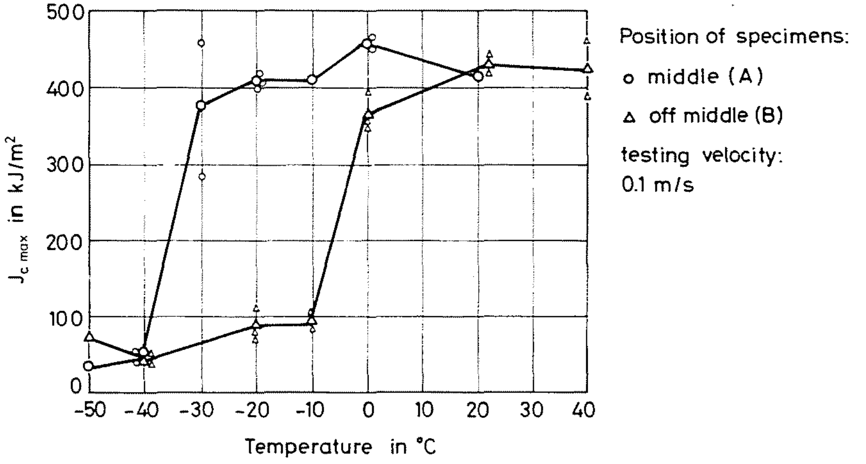


Fig. 9. J-Integral versus testing temperature for precracked Charpy type specimens taken from MAG weld metal [2]

Conclusions

Because of local differences in grain size within a weld bead, fracture properties may vary strongly. The worst properties are to be expected at a section, where the ratio of coarse grained areas to fine grained parts is the highest. According to the arrangement of the welding layers, this unfavourable cross section is not necessarily the middle of the bead. In practice, however, the notch or crack plane of fracture specimens is positioned just at the midsection of the weld bead, as prescribed in various testing instructions. So, the results may be misleading with symmetric weld bead configurations. The experiments have shown up the importance of selecting proper testing conditions. It is well known that fracture behaviour is sensitive to temperature, loading rate and state of stresses (degree of triaxiality). Varying only one factor —usually the temperature—does not assure that slight differences in fracture behaviour can be demonstrated. Such demonstration is mostly probable if plastic—brittle transition occurs, as in our case at the dynamic TBP tests. In general, however, the transition may occur under other circumstances, therefore variable testing methods should be applied.

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