METALLOGRAPHY OF NOTCHED WELDMENT SPECIMENS FRACTURED IN HAZ

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In order to get closer insight into crack propagation through HAZ, metallographic analysis of fractured specimens after test has been performed. Welded joints were produced by submerged arc welding of TSt E460 steel of 460 MPa nominal yield strength. The notch root was positioned in HAZ of Charpy specimen. Overheated area in HAZ can be considered as most critical region, with the toughness of reduced value compared to other microstructures in HAZ, presenting local brittle zones. For this reason crack propagation can be expected in this region. Anyhow, many influencing factors have to be considered in the same time, including very precise positioning of notch root in HAZ.

INTRODUCTION

The welding problems of high-strength low-alloy (HSLA) steels are not completely solved, in-spite of their extended application for many years. One of the basic problems is the behaviour of micro alloying elements in heat-affected-zone (HAZ) and in weld metal (WM) during thermal welding cycles, e.g. possibility of dissolution of nitrides, carbides and carbonitrides of micro alloying elements and their re-precipitation. Generally speaking, if these phases are stable ones, they prevent austenite grains coarsening in HAZ, ensuring in this way required strength and toughness of this region in welded joints. Anyhow, if during the thermal welding cycle the dissolution of above mentioned phases takes place, they can again precipitate during stress relieving, with following reduction in toughness of HAZ (1-3). It has be mentioned that (vanadium rich phases) in are dissoluble in austenite at relatively low temperatures (4). Anyhow, the behaviour of these phases during welding is depended on welding conditions and steel composition and will differ in given circumstances. The nature of basic structure constituents of different HAZ regions has to be taken into account for its significant role in defining of micro alloyed steels welded joints properties.

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The aim of this paper is to consider the dependence of toughness level and crack propagation in HAZ on testing temperature and to evaluate the effects of post-welding stress relieving. The notch root in ISO-V specimen is positioned as precise as possible in the overheated region of HAZ, characterized by heterogeneity of micro structure and properties.

EXPERIMENTAL PROCEDURES

Plates of TSt E460 steel, 20 mm thick, normalized at 900°C/20 min are submerged arc welded after preheating at 100°C in four passes for a X weld shape. For first two passes heat input was 16055 to 14865 J/cm, and for outer passes 15950 to 17410 J/cm. Impact toughness specimens were cut of one half of thickness in the rolling direction, with V notch directed cross to rolling direction. Post welding heat treatment consisted of stress relieving at 580°C for two hours. Instrumented impact test was performed at 20, -20 and -50°C. Optical microscopy was used for identification of microstructures after etching with nital. Vickers HV30 method was applied for hardness measurement.

RESULTS AND DISCUSSION

The results of instrumented impact testing of ISO V specimens made of welded joint and base metal (BM) are presented in Table 1 as depended on testing temperature and heat treatment condition (5). Noticeable drop in impact toughness with decreasing temperature is connected with higher increase of yield strength at decreasing temperature compared to ultimate tensile strength in alloys based on body centered cubic crystals of microconstituents, as it is the case with tested steel (6). This is followed by gradual or step occurrence of brittle behavior in a temperature range, without any visible plastic deformation.

Table 1. Instrumented impact testing results of TSt E460 steel and its welded joint

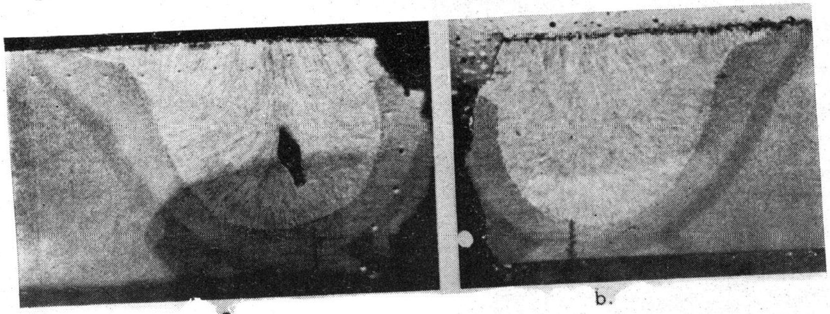
Notch position	Specimen condition	Impact energy , J, at testing temperature 20°C			-20°C			-50°C		
		A_t	A_i	A_p	A_t	A_i	A_p	A_t	A_i	A_p
BM	Normalized	89	40	49	63	33	30	36	26	10
BM	Stress relieved	93	42	51	63	32	31	44	32	12
WM	As-welded	93	34	59	74	30	44	48	24	24
HAZ	As-welded	99	30	69	92	42	50	39	18	21
HAZ	Stress relieved	96	30	66	101	40	61	32	11	21

A-impact energy: t-total, i-initiation, p-propagation

Results from Table 1 show that impact toughness of HAZ starts to reduce at lower temperatures compared to BM and WM, indicating beneficial effect of HAZ heterogeneous structure on impact energy transition temperature. Anyhow, the levels achieved of impact toughness do not differ significantly, except some variations, e.g. for HAZ stress relieved specimens, that can be contributed to the variations in regime during welding. Regarding the energy, required for crack propagation, A_P, that represents microplastic deformation ahead the growing crack front, one can conclude that it decreases with decreasing testing temperature, but with the highest values achieved in all cases in HAZ specimens.

It is possible to conclude that stress relieving does not change impact toughness of welded joints of tested steel. This can be attributed to compensation of effects of toughness decreasing by precipitation hardening and coarsening of phase particles, rich in V, as well as by tempering of non-equilibrium phases, present in HAZ and by dislocations annealing, that contribute to improved steel toughness (7).

The analysis of crack propagation during impact test of welded joints revealed its dependence on testing temperature. At 20°C in an early propagation stage crack front deviates from HAZ into BM, (Fig. 1a); in contrast to this, at -50°C, crack propagates mainly through HAZ, following the plane of notch axis, and only in final stage fracture passed through BM (Fig. 1b). No difference in crack propagation between stress relieved and as-welded specimens could be noticed.



a

b.

Hardness HV30:
1→
200, 196, 237, 272, 232,
222, 224, 219, 230, 226,
225, 254, 285, 273, 252,
234, 221.

Figure 1 Macrosructure of welded joint with fractured area contour of ISO - V specimens: a - tested at 20°C, b -- tested at -50°C.

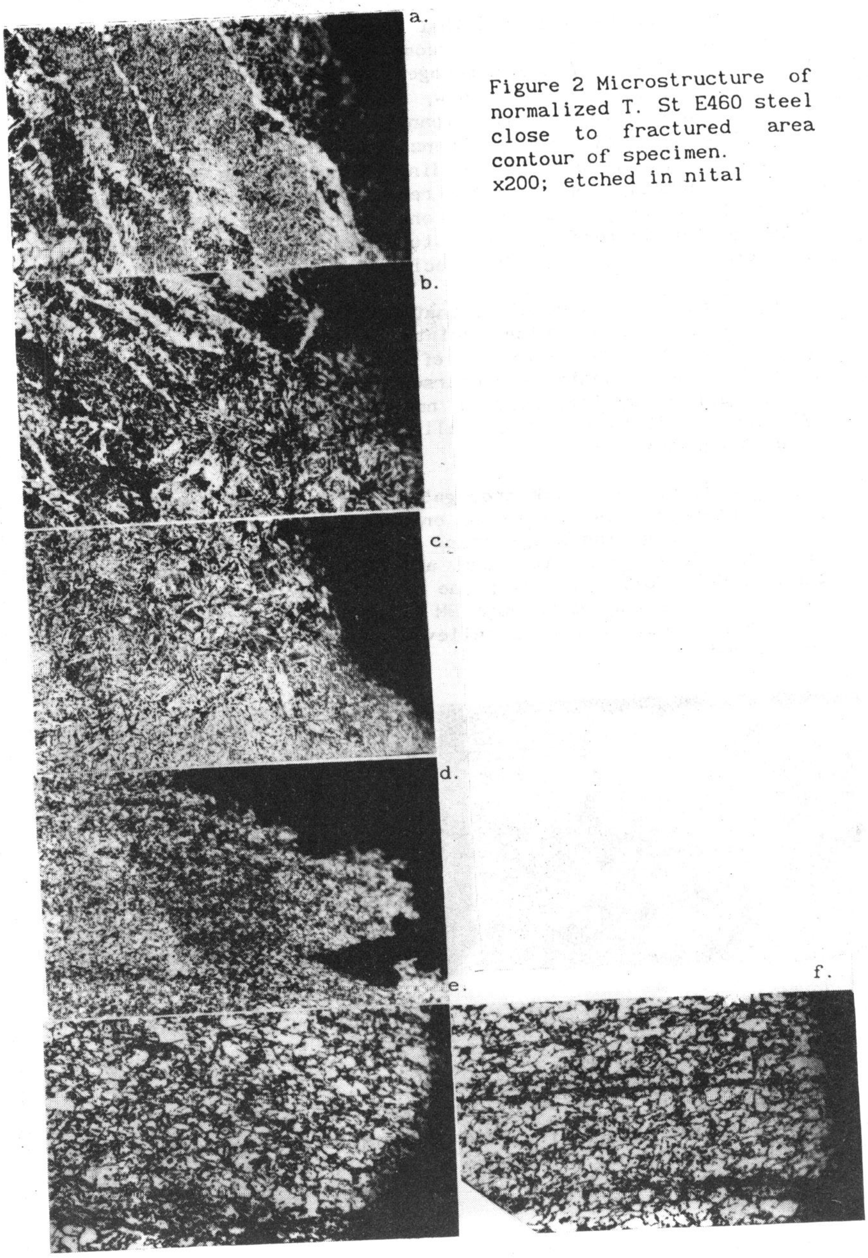
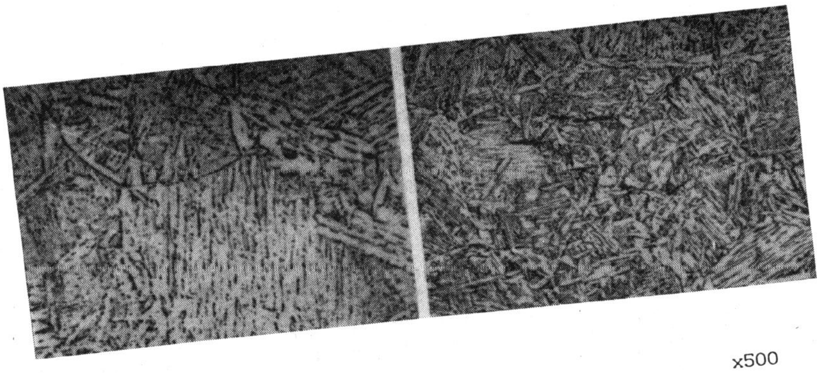


Figure 2 Microstructure of normalized T. St E460 steel close to fractured area contour of specimen. x200; etched in nital

The appearance of microstructure close to fractured area contour in normalized, e.g. as-welded condition, tested at 20°C, (Fig.2a-f) in the same time presents basic microstructure of WM, HAZ and BM, in general. It is clear from given pictures that, in considered case, V notch extended from WM, with ferrite-bainitic (martenzitic) structure (Fig.2a), to coarse grained bainite-martensitic HAZ zone (Fig.2b-c) (8). Starting from notch root, positioned in coarse grained HAZ zone (Fig.2c), fracture developed first through fine grained ferrite-pearlite-bainitic HAZ zone (Fig.2d), and later on through BM. As it is seen from Fig.2e-f, BM structure consists of bands of ferrite and pearlite, the last being mainly in globular form. Hardness values (Fig.1a), agree well with microstructures found in close vicinity of hardness measuring points.

The only noticeable difference in microstructure of stress relieved specimens is expressed by increased precipitation of V reach phases in Fig.3a, that corresponds to HAZ region close to fusion line; for comparison, in Fig.3b, the microstructure in corresponding position of as-welded specimen is presented.



a. x1000 b. x500

Figure 3 Microstructure of stress relieved (a) and normalized (b) T.St E460 steel; etched in nital.

Microstructural test showed that toughness properties of welded joint are better compared to BM, steel TSt E460 (expressed by shifting of transition temperature to lower values and higher level of crack propagation energy) due to presence of higher strength constituents in HAZ microstructure, which plasticity is not reduced significantly due to lower C content in steel. Ductile fracture of specimens with notch in HAZ at 20°C is a consequence of void nucleation and coalescence. Since the crack propagation is followed by significant degree of plastic deformation in that case crack deviates very early from HAZ to BM of higher ductility. Part of fractured area contour, that corresponds to compressed specimen region (Fig.2f), indicates about the contribution in some extent of brittle fracture mechanism in this case (crack displacement from one to the other cleavage plane) due to significant level of strain hardening of BM ferrite-pearlite structure (9). In contrast, based on measured crack propagation energy (Table 1) and fracture appearance on can suppose that cleavage mechanism along certain crystalographic planes after initiated yielding in material is responsible for fracture at -50°C. In this case maximal stress is increased by contribution of strain hardening to the level required for cleavage. During this process stress state changes from full plane strain to generalized plane stress condition. The view of fracture contour at -50°C (Fig.1b) directed to the conclusion that in this testing conditions approximately equal low values of brittle fracture resistance can be attributed to different constituents of heterogeneous HAZ structure and BM as well.

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