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CORRELATION OF ENERGY, DEFORMATION AND FRACTOGRAPHIC PARAMETERS OF MICROALLOYED STEEL WELDED JOINT FRACTURE

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ABSTRACT
Toughness is a complex material characteristic that is viewed from multiple aspects and is influenced by numerous factors. It is very important to have ability to assess toughness, i.e. to determine ductile or brittle material behaviour at any specific time. Beside total impact energy obtained at Charpy instrumented pendulum, the use of additional parameters such as lateral extension measurements and fractographic evaluation of fractured specimens reveals more information of the fracture mechanisms. In this paper, microalloyed steel is welded by MMA process and Charpy specimens were cut from base metal, HAZ and weld metal. The total impact energy at room and lower temperatures, lateral extension of specimens after fracture and fractography of fracture surface were estimeted. The comparasion of all considered parameters enables assessment of welded joint susceptibility to brittle fracture and potential sites of fracture occurrence.
Keywords: impact energy, lateral extension, fractography, welded joint

1. INTRODUCTION
Toughness is a complex material characteristic that is viewed from multiple aspects and is influenced by numerous factors. It is very important to have ability to assess toughness, i.e. to determine ductile or brittle material behaviour at any specific time. Beside total impact energy obtained at Charpy instrumented pendulum, the use of additional parameters such as lateral extension measurements and fractographic evaluation of fractured specimens reveals more information of the fracture mechanisms [1,2,3]. Lateral extension occurs on the specimen sides as a result of lateral plastic deformation. From the literature it is known that there is a linear function of impact energy and lateral expansion, and that both quantities can be taken as a criterion of material susceptibility to brittle fracture[1]. The susceptibility of materials to brittle fracture is smaller if is a higher value of plastic deformation of broken specimen. The comparasion of all considered parameters enables assessment of welded joint susceptibility to brittle fracture and potential sites of fracture occurrence [4].

2. EXPERIMENTAL PROCEDURE
Hot rolled sheets of steel, microalloyed with Nb, V and Ti, 7.2 mm thick, were used for welding. Welding is performed by MMA process using EVB Ni electrode, Ø3.25 mm [5]. Chemical composition of base metal and filler material are given in Table 1.

The standard Charpy specimens with V groove were cut from base metal (BM), heat affected zone (HAZ) and weld metal (WM). Testing was performed on instrumented Charpy pendulum, according to EN 10045-1, i.e ASTM E23-95, at room temperature (20^0C) and lower temperature (-100^0C) [6]. Values of impact energies and diagrams F- τ were obtained.

Table 1. Chemical composition of microalloyed steel and filler material

material	Chemical element, %											
	C	Si	Mn	P	S	Cu	Al	Nb	Ti	Cr	Ni	V
Micro-alloyed steel	0.05	0.32	1.28	0.012	0.005	0.03	0.049	0.045	0.02	-	-	0.054
EVB Ni	0,07	0,5	1,4								1,1	

3. RESULTS AND DISCUSSION

In order to obtain a more complete assessment of material susceptibility to brittle fracture, the values of specimens lateral extension were measured ($\Delta b=b_1-b_0$, where b_0 is initial specimen width and b_1 maximum specimen width after fracture).

For ease comparison of energy, deformation and fractographic parameters, comparative tables were made for all three zones of the welded joint at both investigated temperatures, Table 2 and 3.

Table 2. Correlation of energy, deformation and fractographic parameters for welded joint at 20^0C

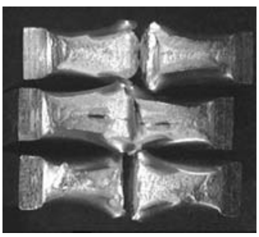
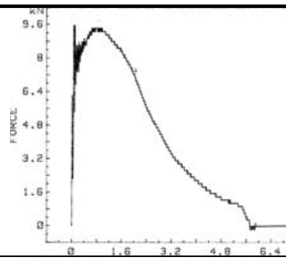
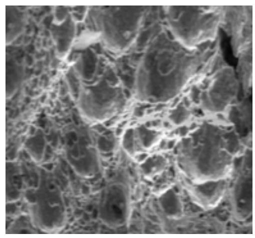
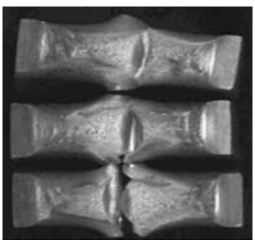
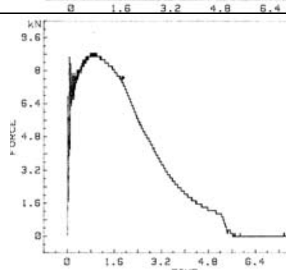
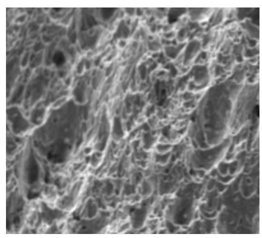
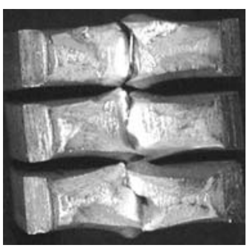
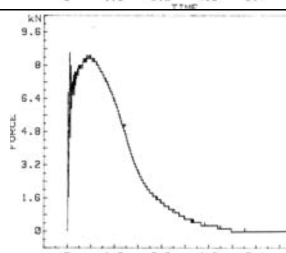
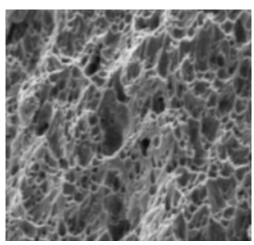
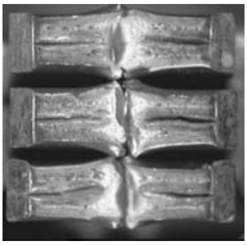
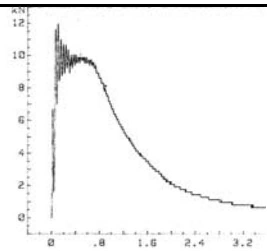
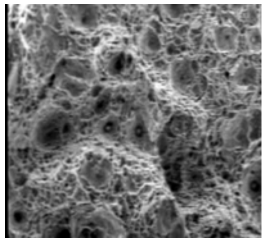
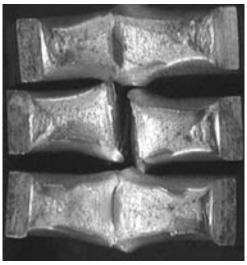
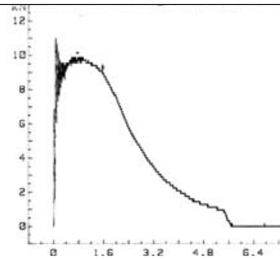
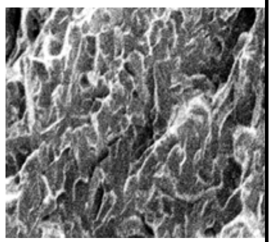
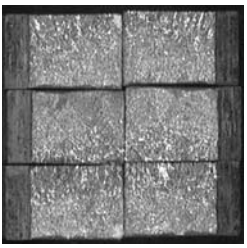
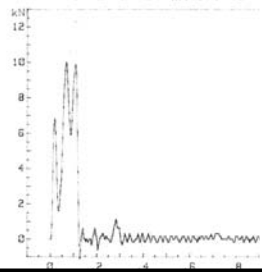
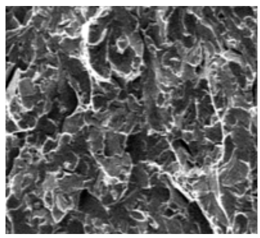
	E, J / Δb, mm	Deformation	Diagram F-τ	Fractography
BM	126 / 1.6			
HAZ	123 / 1.6			
WM	83 / 1.4			

Table 3. Correlation of energy, deformation and fractographic parameters for welded joint at -100^{0}C

	E, (J) Δb,(mm)	Deformation	Diagram F-τ	Fractography
BM	78 1.1			
HAZ	129 1.5			
WM	6 0.1			

At room temperature there is a good compliance of all parameters. Almost identical diagram shapes F-τ diagrams obtained on instrumented Charpy pendulum for BM and HAZ are confirmed by approximately same values of impact energies, then by maximum values of lateral extension and finally by fractographic analysis where in both zones is present pure ductile transgranular fracture with typical pits and stable crack growth. In the diagram F-τ for weld metal can be seen smaller area under the curve, as regards to lower impact energy. Specimen deformation is changing analogous to impact energy, while in fractographic analysis pure transgranular ductile fracture is present, with the possible presence of secondary cracks.

At temperature -100^{0}C HAZ toughness does not decline, but in base metal toughness is significantly reduced. (78 J). The weld metal has reached a completely brittle state and fracture occurs practically without energy consumption (6J). That is confirmed by the values of lateral extension, which changes linearly with impact energy. On the contrary, by analysis of the diagram F-τ is concluded that there was no significant decrease in the toughness of the base metal. Visual inspection of fracture surfaces clearly shows the proportion of brittle fracture, i.e. there is still transgranular ductile dimple fracture, but with a clearly defined area of unstable crack growth. Although that's not confirmed through impact energy, in the HAZ is present brittle transgranular cleavage fracture in the second half of the specimen. In the weld metal parameters are all agreed: the diagram F-τ belongs to the unstable crack growth, cleavage fracture mechanism and low values of impact energy and lateral extension [7].

4. CONCLUSIONS

On the base of obtained experimental results and their analysis, the following is concluded:

1. The value of impact energy obtained by Charpy instrumented pendulum is not the only toughness parameter. By measuring of lateral extension of specimen after fracture, fractography analysis of fracture surface and by estimation the shape of diagram F-τ, additional data about fracture mechanism can be obtained.
2. The assessment of material susceptibility to brittle fracture on the basis of one parameter is valid in cases of pronounced ductility (room temperature for BM, WM and HAZ) or pronounced brittleness. In these conditions all the considered parameters are consistent, so one of them is sufficient for evaluation.
3. In the case of mixed fracture, it was shown that the offered parameters are not always mutually consistent, and none of the available parameters alone can not completely define the process and mechanism of fracture. Therefore the detailed material toughness analysis necessary must include: value of Charpy impact energy, diagram F-τ and fractographic analysis of fracture mechanism. The comparasion of all considered parameters enables assessment of material susceptibility to brittle fracture and potential sites of fracture occurrence.

5. ACKNOWLEDGEMENT

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