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IMPACT TOUGHNESS OF SIMAXX 1000 STEEL WELDED JOINTS

UDARNA ŽILAVOST ZAVARENIH SPOJEVA ČELIKA SIMAXX 1000

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Keywords
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- impact toughness
- welded joint zones
- ductile-to-brittle transition temperature

Ključne reči
- SIMAXX 1000
- udarna žilavost
- zone zavarenog spoja
- temperatura prelaska u krti lom

Abstract

The behaviour of welded joints of low-alloy steel with ultra-high strength SIMAXX 1000 steel at fracture due to impact load is analysed. For the impact test, an instrumented Charpy pendulum is used to separate the total energy into energy for the formation and energy of crack growth. Standard test specimens with a crack in the base metal (OM), heat affected zone (HAZ), and weld metal (MŠ) are used to determine the influence of the heterogeneous microstructure of the welded joint. The effect of low temperature down to –60 °C is also analysed to confirm that SIMAXX 1000 steel can also be used at low temperatures. Toward this aim the ductile-to-brittle transition temperature is determined.

Izvod

Analizirano je ponašanje zavarenih spojeva niskolegiranog čelika ultra visoke jačine, SIMAXX 1000, pri lomu usled udarnog opterećenja. Za udarno ispitivanje je korišćeno instrumentirano Šarpijevo klatno, u cilju razdvajanja ukupne energije na energije nastajanja i rasta prsline. Korišćene su standardne epruvete sa zarezom u osnovnom metalu (OM), zoni uticaja toplote (ZUT) i u metalu šava (MŠ), kako bi se utvrdio uticaj heterogene mikrostrukture zavarenog spoja. Uticaj niske temperature do –60 °C je takođe analiziran, kako bi se potvrdilo da je čelik SIMAXX 1000 upotrebljiv i na niskim temperaturama. U tom cilju je određena temperatura prelaska u krti lom.

INTRODUCTION

Application of UHSLA steels is growing in recent years as their properties are improving, especially yield strength that has reached 1,000 MPa recently, e.g., SIMAXX 1000, /1/. Still, one has to be careful about the toughness, particularly in case of low temperature use of these steels. Thus, the Ductile-to-Brittle Transition Temperature (DBTT) is of equal importance. Also, one should consider separation of total Charpy energy into the energy for crack initiation and the energy for crack propagation to get the full insight into crack resistance of SIMAXX 1000 and its welded joint, /2/.

Another aspect of this issue is the heterogeneity of welded joint properties due to different microstructures at different zones (base metal - BM, weld metal - WM and the heat-affected-zone - HAZ), which needs to be accounted for, /3-8/. To get the complete insight into the behaviour of welded joints in these conditions, the crack initiation energy and the crack propagation energy, as components of the total impact energy, should be considered. These issues are even more pronounced in the case of UHSLA, since their microstructure is more susceptible to cracking than HSLA steels with lower yield strength (460-690 MPa), /9/. Therefore, the evaluation of DBTT is of utmost interest for potential applications at low temperatures, as is described in a couple of recent papers, /10-13/.

MATERIAL AND WELDING

The SIMAXX 1000 is an UHSLA steel with minimal yield strength (YS) of 850-960 MPa, depending on the thickness, as defined by EN 10025-6, /14/. Optimal combination of high strength, toughness, and weldability makes SIMAXX 1000 competitive for applications where high strength-to-weight ratio is crucial. Chemical composition and mechanical properties of SIMAXX 1000 are shown in Tables 1 and 2.

Welding is done by SMAW (MAG) with electrode wire Union X96, diameter 1 mm, to produce a 'K' welded joint of 15 mm thickness, in 5 runs.

Nominal mechanical properties and chemical composition of the filler material are shown in Tables 3 and 4. As a shielding gas, the mixture 82 CO_2-18 Ar is used.

Table 1. Chemical composition of the tested batch of steel SIMAX 1000.

C	Si	Mn	P	S	Cu	Al	Cr	Mo	Ni	N	Al	V	Nb	Ti	W
0.175	0.277	1.02	0.008	<0,004	0.206	0.045	0.54	0.445	0.267	0.004	0.045	0.008	0.026	0.021	0.002

Table 2. Results of tensile properties of BM specimens tested at low temperatures.

Test temperature (°C)	Yield strength $R_{p0.2}$ (MPa)	Tensile strength R_m (MPa)	Elongation A (%)
20	988-1006	1033	14.2
–40	1028	1066	14.0

Table 3. Chemical composition of filler metal Union X96.

% wt.						
C	Si	Mn	Ni	Cr	Ni	Mo
0.12	0.82	1.90	1.1	0.45	2.35	0.55

Table 4. Mechanical properties of filler metal Union X96.

Yield strength $R_{p0.2}$ (MPa) min.	Tensile strength R_m (MPa) min.	Elongation A (%) min.	Impact energy KV (J) at 20 °C min.
930	980	14	80

IMPACT TESTING

Standard Charpy specimens are used for impact tests, /10/, Three groups of specimens are tested (BM, WM and HAZ) at four different temperatures (–60 °C, –40 °C, –20 °C, +20 °C) to evaluate DBTT for all welded joint zones.

Each of 12 groups consisted of at least 3 specimens. Results of impact testing are shown in Tables 5-7, whereas the results for DBTT are shown in Fig. 1a-c, indicating –67 °C for BM, –58 °C for WM and –65 °C for HAZ.

DISCUSSION

To start the discussion, let us mention that the expected undermatching effect, due to lower YS of electrode wire compared to BM, was not achieved. Such design is recommended in the case of UHSLA steels, /13, 14/ to avoid problems with cold cracking. Nevertheless, the welded joint turned out to be even-matched or slightly overmatched probably due to cooling rate and the resulting microstructure, which shall be the topic of another paper, not available now.

The notch location effect on total impact energy (Tables 5-7) indicates the highest values in BM, as expected, and a relatively small reduction of its values in WM and HAZ, the latter being surprisingly close to the BM values.

Table 5. Values of impact energy in the BM.

Specimen designation	Temperature (°C)	Initiation energy W_i (J)	Propagation energy W_p (J)	Total impact energy W_t (J)
BM - 1A	–60	4.1	27.9	32.0
BM - 2A		5.1	30.5	36.6
BM - 3A		5.1	28.5	33.6
BM - 1B	–40	34.2	35.3	68.4
BM - 2B		31.3	38.5	71.2
BM - 3B		31.4	36.7	69.7
BM - 1C	–20	45.7	39.5	85.2
BM - 2C		54.1	42.4	96.5
BM - 3C		49.1	40.1	89.2
BM – 1D	20	85.7	57.7	143.4
BM – 2D		91.5	58.2	149.7
BM – 3D		91.5	58.9	150.4

Table 6. Values of impact energy in the WM.

Specimen designation	Temperature (°C)	Initiation energy W_i (J)	Propagation energy W_p (J)	Total impact energy W_t (J)
WM - 1A	–60	4.5	20.2	24.7
WM - 2A		4.8	23.9	28.7
WM - 3A		3.2	23.1	26.3
WM - 1B	–40	17.1	40.5	57.6
WM - 2B		15.5	37.9	53.4
WM - 3B		20.0	36.4	56.4
WM - 1C	–20	19.8	54.3	74.1
WM - 2C		21.3	55.6	76.9
WM - 3C		18.4	52.9	71.3
WM – 1D	20	37.5	57.6	95.1
WM – 2D		38.2	55.2	93.4
WM – 3D		37.8	52.1	89.9

Table 7. Values of impact energy in the HAZ.

Specimen designation	Temperature (°C)	Initiation energy W_i (J)	Propagation energy W_p (J)	Total impact energy W_t (J)
HAZ - 1A	-60	5.6	26.5	32.1
HAZ - 2A		4.3	25.2	29.5
HAZ - 3A		8.0	26.9	34.9
HAZ - 1B	-40	25.3	45.4	70.7
HAZ - 2B		24.8	44.1	68.9
HAZ - 3B		24.3	41.1	65.4
HAZ - 1C	-20	40.8	48.3	89.1
HAZ - 2C		44.9	50.8	95.7
HAZ - 3C		39.0	45.8	84.8
HAZ – 1D	20	87.3	53.8	141.1
HAZ – 2D		90.6	57.2	147.8
HAZ – 3D		84.2	52.1	136.3

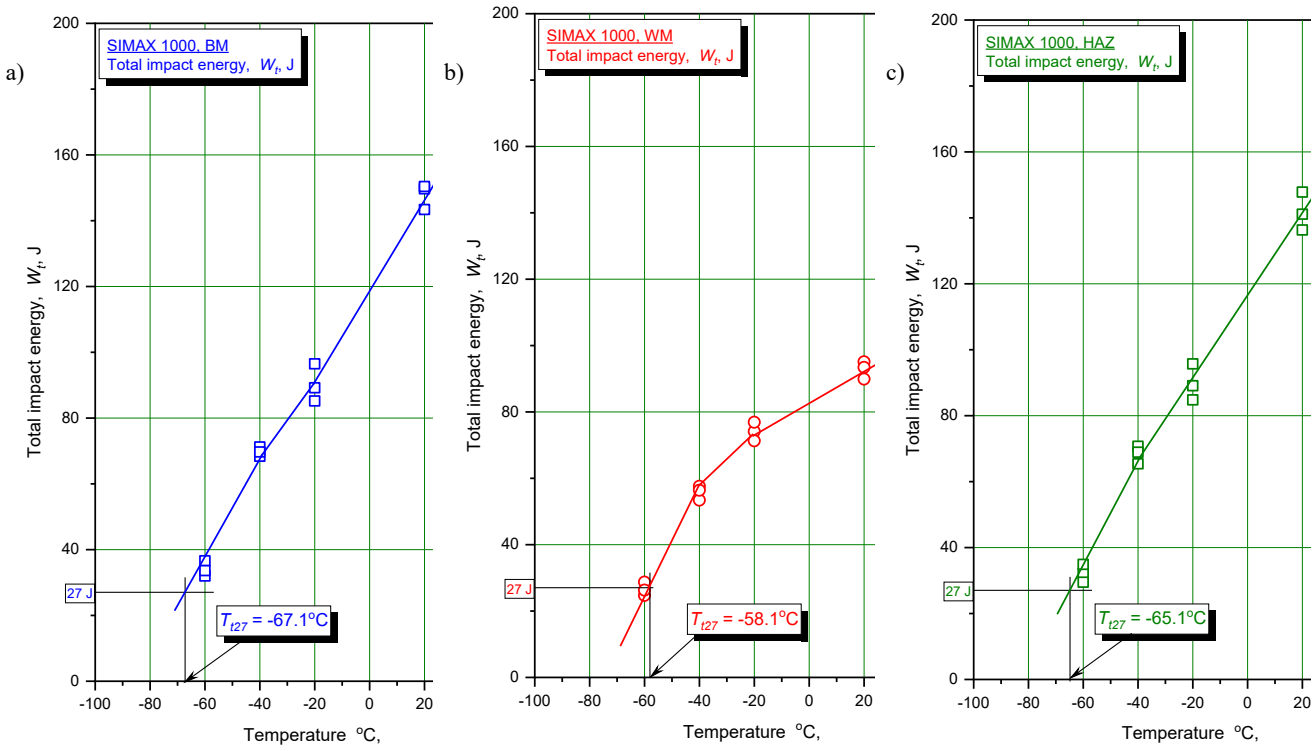

Figure 1. Dependence of total impact energy W_t on temperature: a) BM; b) WM; c) HAZ.

Total impact energy W_t decreases in a successive manner from room temperature to –60 °C for all welded joint zones (BM, WM and HAZ). Influence of test temperature is most significant for specimens with the notch in the WM, but the difference in comparison with BM is small, and yet smaller when HAZ is compared to BM. One should keep in mind that the DBTT defined only on the total impact energy may not be always relevant. Namely, if only crack propagation energy is considered, in other words, if a crack already exists in a welded joint (no energy is needed for initiation), the DBTT typically increases. Nevertheless, in the case of welded joints made of SIMAXX1000, this increase is only a few degrees, since the initiation energy is very small. Therefore, even though this steel is sensitive to crack initiation, its DBTT is still satisfying.

CONCLUSIONS

The goal of this paper is to determine behaviour of UHSLA steel SIMAX1000 under impact loading, for each welded joint zone (BM, HAZ and WM) tested at different temperatures, from +20 °C down to –60 °C.

Based on the obtained results, it can be concluded that the WM is the weakest link in an otherwise strong chain of welded joint zones, providing the DBTT is close to –60 °C, but only if there is no pre-existing crack. Therefore, if the operating temperature is close to –60 °C, the 100 % non-destructive testing has to be performed.

In any case, it is obvious that UHSLA steel SIMAXX 1000 has sufficient impact toughness for use in critical structures, including at low operating temperature.

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