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TEMPERATURE AND STRESS CONCENTRATION EFFECTS ON CRACK INITIATION AND PROPAGATION ENERGIES OF A DUPLEX STEEL WELDMENTS

UTICAJI TEMPERATURE I KONCENTRACIJE NAPONA NA ENERGIJE NASTANKA I RASTA PRSLINE KOD ZAVARENIH SPOJEVA DUPLEKS ČELIKA

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Keywords
- crack initiation and propagation energy
- duplex steel UNS S32750
- temperature effects
- stress concentration effects

Abstract

This paper presents the effect of temperature on values of energies for crack initiation and propagation for three zones of the welded joint using Charpy specimens, both standard, and those with additional cracks, to follow also the effect of stress concentration. Welded joints of the super duplex steel UNS S32750 made by gas tungsten arc welding process are used in this investigation.

Ključne reči
- energija nastanka i rasta prsline
- dupleks čelik UNS S32750
- uticaj temperature
- uticaj koncentracije napona

Izvod

U ovom radu prikazan je uticaj temperature na energiju za nastanak i rast prsline za sve tri zone zavarenog spoja, korišćenjem Šarpi epruveta, kako standardnih, tako i onih sa dodatnim prslinama, kako bi se pratio i uticaj koncentracije napona. U ovom istraživanju korišćeni su zavareni spojevi od super dupleks čelika UNS S32750 dobijeni TIG postupkom.

INTRODUCTION

After the introduction of impact toughness testing, defined as the total energy to break a notched specimen by a single pendulum strike /1, 2/, the next important development was the introduction of instrumented pendulum, enabling the separation of the total energy into the energy for crack initiation, A_i, and crack propagation, A_p /3, 4/. The most common way to do it is by using the maximum force at a force vs. displacement or time diagram, with a reasoning that energy for crack initiation is the area below the curve from zero point to maximal force, while the energy for crack propagation is the area below the curve after the maximal point, as explained in more detail in /3, 4/.

Welded joints are of special interest when crack resistance is analysed, since energies for crack initiation and propagation significantly differ in their different zones - base metal (BM), weld metal (WM), and heat-affected-zone (HAZ) /5-11/. Welded joints made of steel SA-387 Gr. 91 were analysed in /5-8/ with a focus on temperature and exploitation effects under static or impact loading. Similar investigation is presented in /9-11/ for duplex stainless steel S32750, including also stress concentration effects, /9/.

Here we consider duplex stainless steel S32750, often used in aggressive corrosion environments, /10/. Results of Charpy impact testing are presented in /9-11/, including temperature and material heterogeneity, as well as determination of so-called stress concentration factor (SCF), /9, 10/, obtained by using cracked Charpy specimens.

The paper presents the effect of temperature on values of energies for crack initiation and propagation for three zones of welded joint using Charpy specimens, both standard ones, and those with additional cracks, to follow also their effect, i.e., the effect of stress concentration.

MATERIALS AND METHODS

Welded joints of the super duplex steel UNS S32750 are produced by Gas Tungsten Arc Welding (GTAW) process, using TIG 22/9/3 LN wire. More details about the process and welded joints are presented in /10/.

Standard Charpy V notched specimens are used to determine total impact energy, as well as energies for crack initiation and propagation on instrumented Charpy pendulum, /13/. Testing was conducted in accordance with standard EN ISO 148-1:2017, /12/, at different temperatures: -40 °C, -60 °C and -80 °C. The notch tip is positioned in three different zones, BM, WM, and HAZ, Fig. 1, /14/.

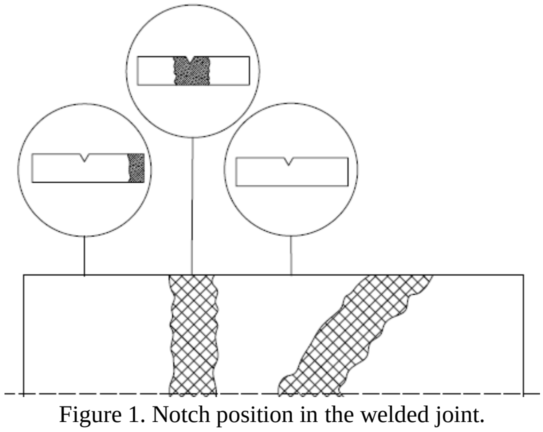


Figure 1. Notch position in the welded joint.

Charpy V specimens with additional cracks positioned in BM, WM, and HAZ, were also tested on instrumented pendulum at different temperatures (-40 °C, -60 °C and -80 °C). Fatigue crack lengths ranged from 1 to 5.5 mm, as made using the FRACTOMAT, /10/. More details of material and methods are given in /11/.

RESULTS

Force versus time diagrams obtained by testing standard Charpy V notch specimens are shown in /10/ for all welded joint zones at different testing temperatures, while here the force-time diagrams are shown for representative Charpy V notch specimens with additional cracks in BM, WM, and HAZ, Figs. 2-4, in respect. Results for crack initiation and propagation energies are shown in Tables 1-3. As expected, the highest values of energies are obtained for the BM, followed by the WM, while HAZ values are far below.

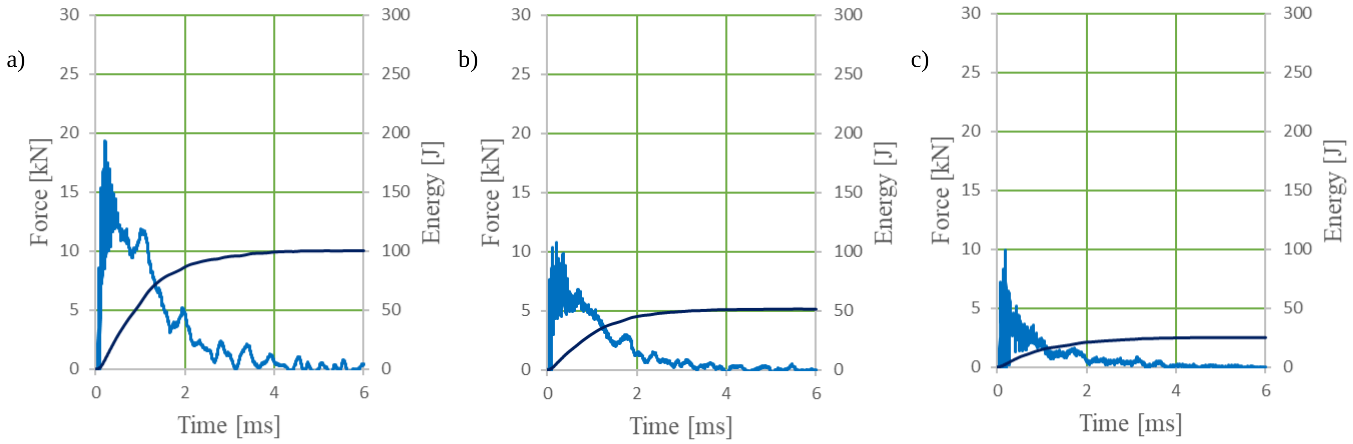


Figure 2. Force and energy vs. time diagrams for BM: a) -40 °C, b) -60 °C, c) -80 °C.

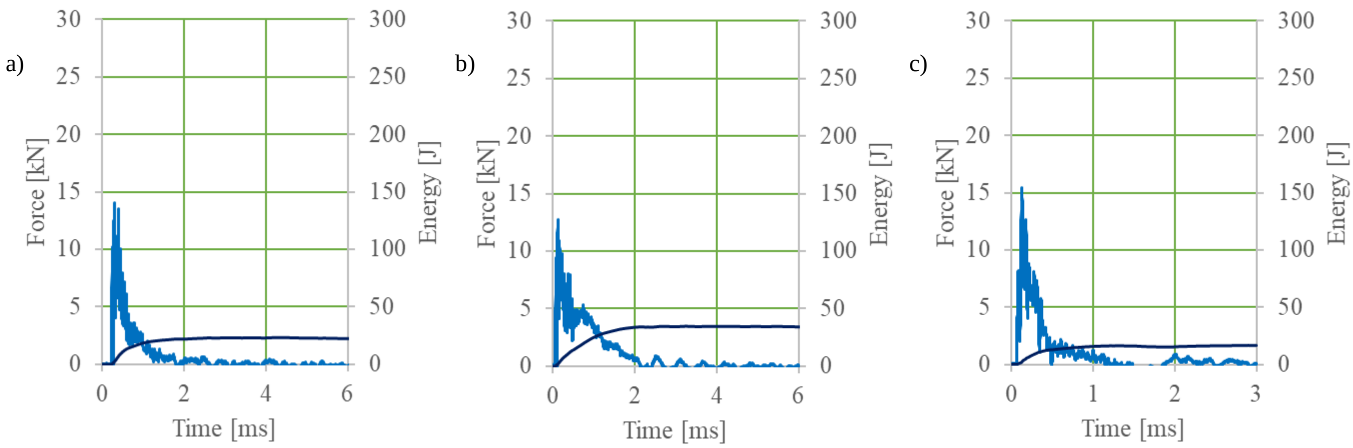


Figure 3. Force and energy vs. time diagrams for WM: a) -40 °C, b) -60 °C, c) -80 °C.

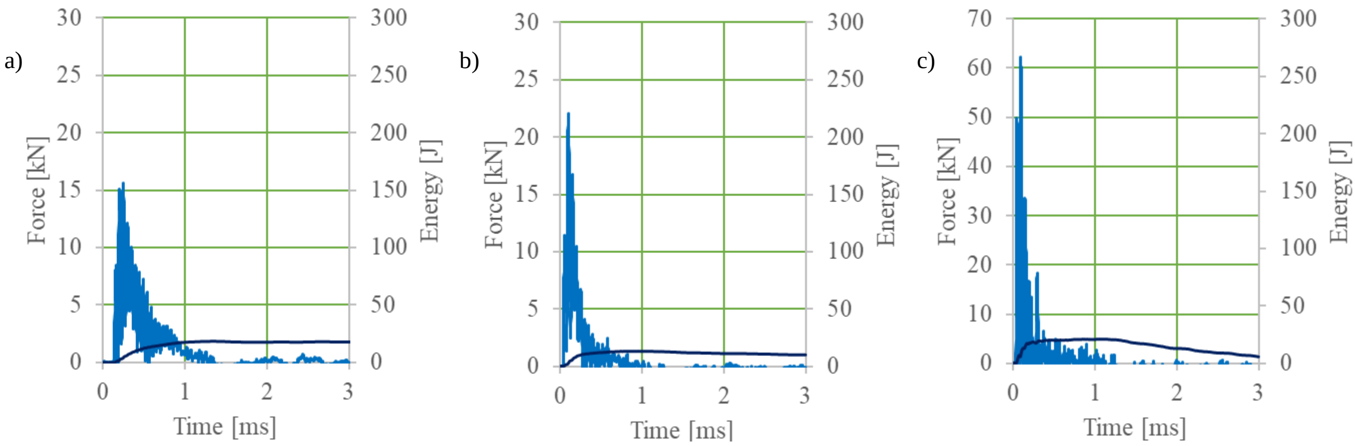


Figure 4. Force and energy vs. time diagrams for HAZ: a) -40 °C, b) -60 °C, c) -80 °C.

Table 1. Energy distribution - BM.

Temp. °C	Specimen with V notch			Specimen with V notch and crack		
	A_{tot} (J)	A_i (J)	A_p (J)	A_{tot} (J)	A_i (J)	A_p (J)
-80	82	17	65	23	2	21
-60	125	25	100	48	3	45
-40	201	45	156	122	14	107

Table 2. Energy distribution - WM.

Temp. °C	Specimen with V notch			Specimen with V notch and crack		
	A_{tot} (J)	A_i (J)	A_p (J)	A_{tot} (J)	A_i (J)	A_p (J)
-80	27	9	18	12	3	10
-60	34	7	27	33	3	31
-40	112	40	68	36	7	30

Table 3. Energy distribution – HAZ.

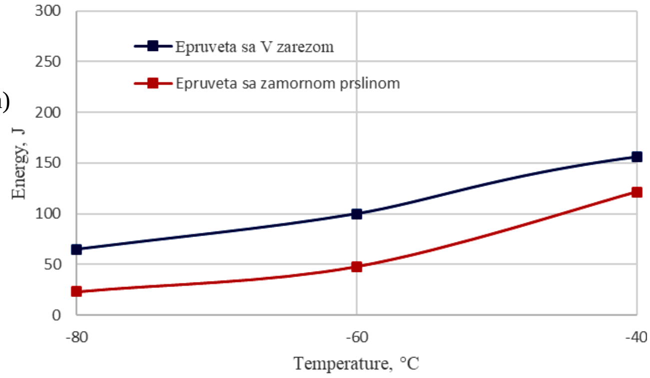
Temp. °C	Specimen with V notch			Specimen with V notch and crack		
	A_{tot} (J)	A_i (J)	A_p (J)	A_{tot} (J)	A_i (J)	A_p (J)
-80	18	5	13	15	4	11
-60	20	6	15	11	4	7
-40	32	11	21	20	4	16

DISCUSSION

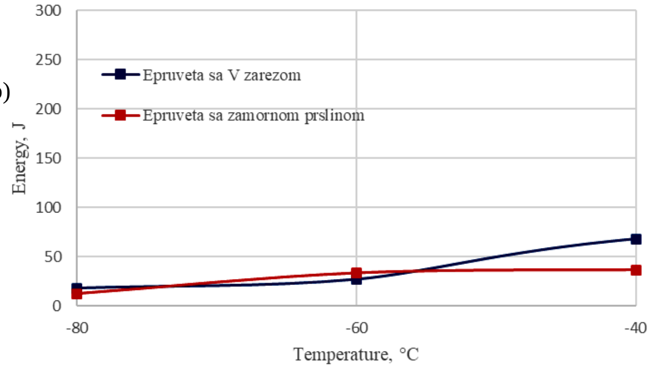
As the temperature decreases, the differences in impact toughness are getting smaller, so the assumption is that if additional fatigue crack exists, there is no crack formation energy A_i, but only A_p. To analyse this in more detail, Fig. 5 can be used which shows the mean values of impact energy for two types of specimens: standard with V-notch and non-standard with an additional fatigue crack. The distribution for HAZ has been repeated in a different scale to better show the differences.

The analysis was done for temperatures -80 °C, -60 °C and -40 °C, when brittle fracture is expected. As one can see, differences between two the types of specimens are significant only for the BM, i.e., when there is a significant plasticity and mixed type of fracture.

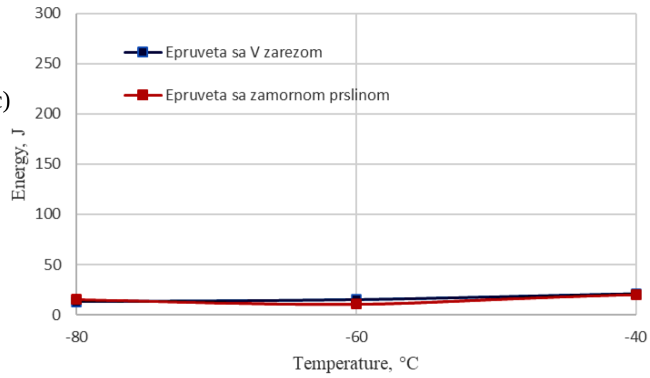
a)



b)



c)



d)

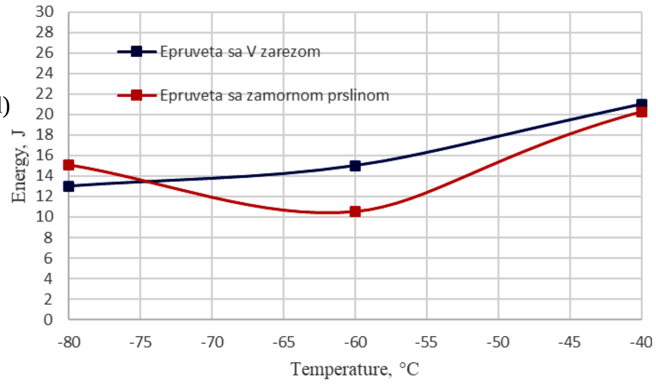


Figure 5. Distribution of total energy: a) BM, b) WM, c) HAZ, d) HAZ with a different scale.

In respect to energies for crack initiation and propagation, one can see from Tables 1-3 that energy for crack initiation is indeed significantly reduced when non-standard specimens with additional crack are compared to standard ones. To explain why there is still some energy for crack initiation, one should consider the method of energy separation that defines energy for crack initiation as the surface below the force-time curve. Since the force cannot jump to the maximal value in 0 time, this area will always exist, however small it would be.

CONCLUSIONS

Based on the presented results, one can conclude the following:

- temperature effect is not much pronounced in respect to separation of energies;
- crack, i.e., stress concentration effect is much more pronounced, as expected, reducing significantly the energy for crack initiation;
- nil-ductility (transition) temperature, corresponding to the total impact energy 27 J, is -110 °C for BM, -80 °C for WM and -50 °C for HAZ, limiting the use of duplex steels to somewhat higher temperature than expected.

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