

INFLUENCE OF TEMPERATURE ON IMPACT TOUGHNESS OF HSLA STEELS UTICAJ TEMPERATURE NA UDARNU ŽILAVOST NISKOLEGIRANOG ČELIKA POVIŠENE ČVRSTOĆE

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- impact toughness
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- high strength low-alloy steel

Abstract

The aim of this paper is to present the influence of different temperatures on the impact toughness of welded joint of high strength low-alloy steel. The results of impact tests for all three constituents of the manual arc welded joint of NN-70 steel at temperatures range from 20 °C to -100 °C are presented. It has been shown that impact tests of high-strength low-alloy (HSLA) steels at room and lower temperatures indicate that temperature significantly affects the toughness of high-strength low-alloy steels in the context that lowering the test temperature leads to creation of brittle fracture in the form of a successive decrease in total impact energy. This indicator is very important in the further design and exploitation of welded steel structures.

INTRODUCTION

In many production processes, as well as in the exploitation of machine components and structures, materials are exposed to impact loads. The strain rate is high and the material shows much more brittle behaviour than it does under static loading, /1/. Properties of parent material and especially welded joint that are submitted to impact load differ from the properties obtained in case of static force effect. Properly with dynamic loads, an important factor is toughness as one of the mechanical properties of the material, which is defined as the energy that needs to be used to cause the destruction of the material's structure, respectively, to achieve a fracture.

Impact toughness testing is one of the oldest methods of impact testing, as stated in the paper written by Popović and Sedmak, /2/. Using instrumented Charpy pendulum, more precisely by installing a device that records the change of force and energy with the test time, significant progress was made in the development of impact toughness testing. The results of the test on the instrumented Charpy pendulum allow complete monitoring and understanding of the fracture mechanism and the separation of the total impact energy into the crack initiation energy and crack propagation energy. Further, advantages of this procedure are easy sample preparation, simplicity, speed and low test costs.

The well-known advantages of impact toughness testing as well as the requirements for the exploitation of structures made of HSLA steel welded joints were discussed in the

Ključne reči

- udarna žilavost
- energija nastanka i rasta prslina
- zavareni spoj
- niskolegirani čelik povišene čvrstoće

Izvod

Cilj ovog rada je da prikaže uticaj različitih temperatura ispitivanja na udarnu žilavost zavarenog spoja niskolegiranih čelika povišene čvrstoće. Prikazani su rezultati udarnih ispitivanja za sva tri konstituenta ručno elektrolučnog zavarenog spoja NN-70 čelika pri temperaturama u rasponu od 20 °C do -100 °C. Pokazalo se da udarna ispitivanja niskolegiranih čelika povišene čvrstoće na sobnoj i nižim temperaturama ukazuju da temperatura značajno utiče na žilavost niskolegiranih čelika povišene čvrstoće u kontekstu da sniženje temperature ispitivanja pogoduje stvaranju krug loma u vidu sukcesivnog opadanja ukupne energije udara. Ovakav pokazatelj je veoma značajan u daljem projektovanju i eksploataciji zavarenih čeličnih konstrukcija.

paper written by Grabulov and Blačić, /3/, which are also the subject of this paper. Tests were performed for all zones of welded joint (base metal, weld metal and heat-affected zone) because the requirements and criteria for the integrity and life of the structures are very important due to the consequences of structural damage and possible major damage.

Based on the above mentioned, it is easy to conclude that it is necessary to emphasize the testing of impact toughness in laboratory conditions of HSLA welded joints at different temperatures. This is the only way to get closer to the real dynamic loads of structures during exploitation and determine the resistance to brittle fracture of the welded joint of HSLA steel as a heterogeneous microstructure.

CHARPY IMPACT TESTING

For this impact testing, welded joint of high strength low-alloy steel (HSLA) Nionikral-70 (NN-70) is developed, as a result of cooperation between Military Technical Institute in Žarkovo (VTI Serbia) and ironworks Jesenice from Jesenice (Slovenia). Specimens for impact toughness testing of rectangular cross section, Fig. 1, are made of high strength low-alloy steel welded plates NN-70 with thickness of 20 mm. Plates were welded by shielded manual arc butt weld using the electrode EVB 75 - Jesenice (Slovenia). The preheating temperature was 170 °C.

A total of 29 Charpy test specimens for impact toughness testing (PM-11, WM-9 and HAZ-9) were made, with standard dimensions of 55x10x10 mm and notch of 2 mm depth.

Table 1. shows chemical composition of NN-70 and mechanical properties.

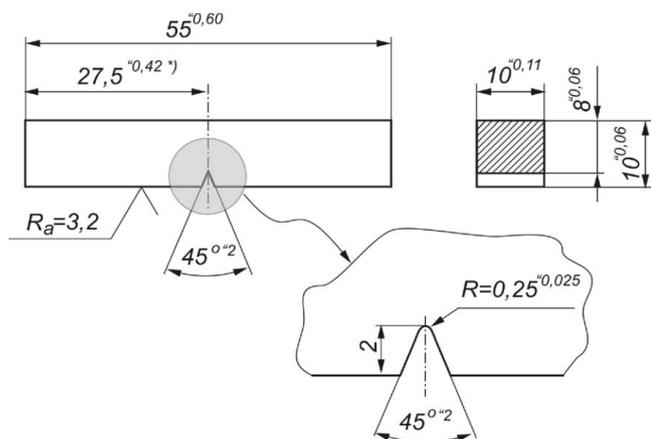


Figure 1. Specimen for Charpy impact testing.

Table 1. Chemical composition (% wt) and mechanical properties of NN-70.

C	Si	Mn	P	S	Cr	Ni	Cu
0.106	0.209	0.220	0.005	0.017	1.258	2.361	0.246
Yield strength (MPa)					645		
Ultimate strength (MPa)					914		
Elongation (%)					22.4		

To determine the total impact energy and its components - crack initiation and crack propagation energy, impact tests of Charpy specimens with notches in parent metal, weld metal and the heat affected zone are performed. The test procedure and specimen sizes and shape, as shown in Fig. 1, are defined according to SRPS EN 10045-1 and SRPS EN 10045-2 or ASTM E23-02, /4-7/. Impact testing is performed on the SCHENCK TREBEL 150-300 J, instrumented Charpy pendulum, at different temperatures (20 °C, -20 °C, -40 °C, -60 °C, -80 °C and -100 °C), depending of on the constituent of the welded joint. The position of notch is according to EN 875, /8/. Using Charpy specimens on the SCHENCK TREBEL, diagrams force-time are constructed (Fig. 2).

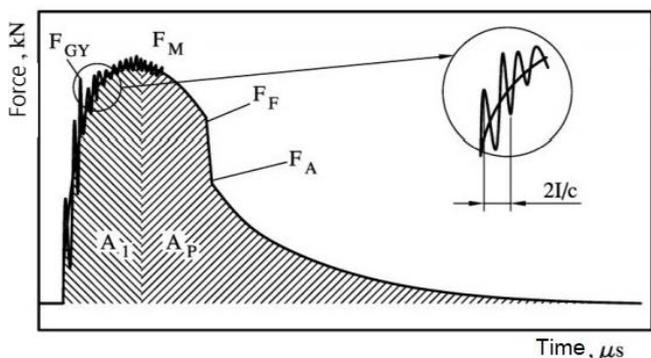


Figure 3. Force-time diagram.

Using force-time diagram the total impact energy is obtained. Total impact energy is necessary for specimen fracture and is divided into two parts: crack initiation energy A_I and crack propagation energy A_P , Fig. 2.

Diagrams of parent metal of NN-70 in Fig. 3 show force-time and energy-time curves for temperatures 20 °C, -20 °C, -60 °C and -100 °C, respectively.

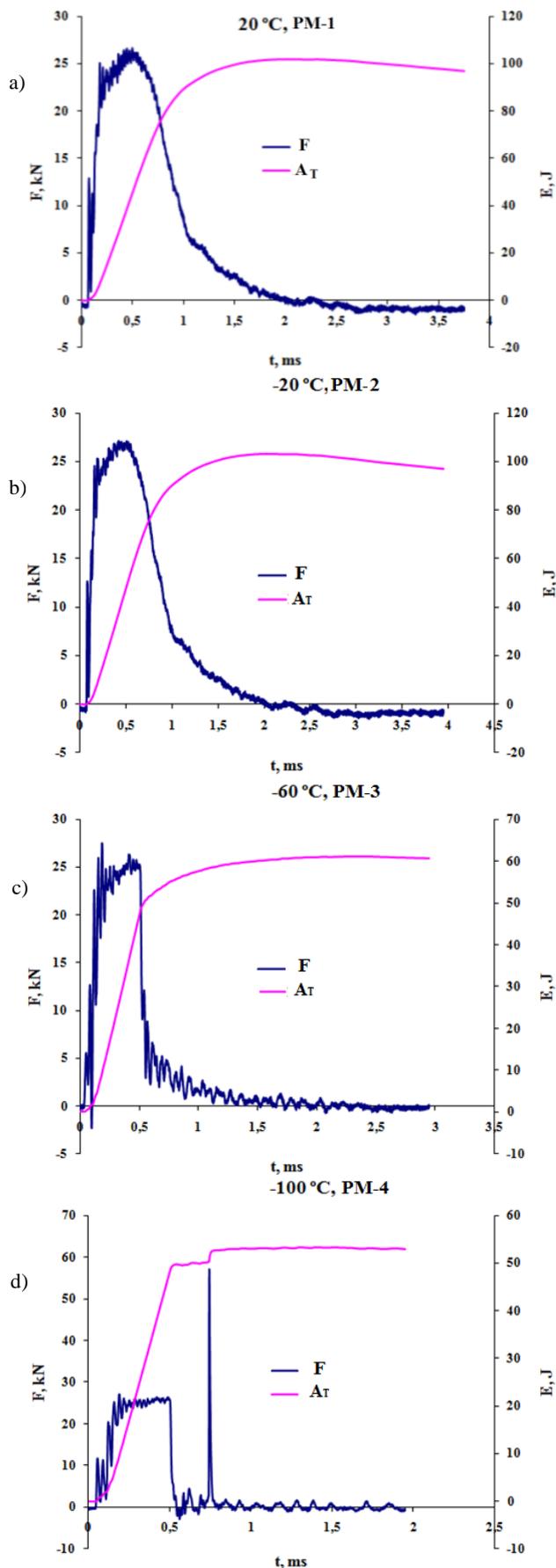


Figure 4. Diagrams force-time and energy-time for PM at 20 °C, -20 °C, -60 °C, and -100 °C (a, b, c, and d).

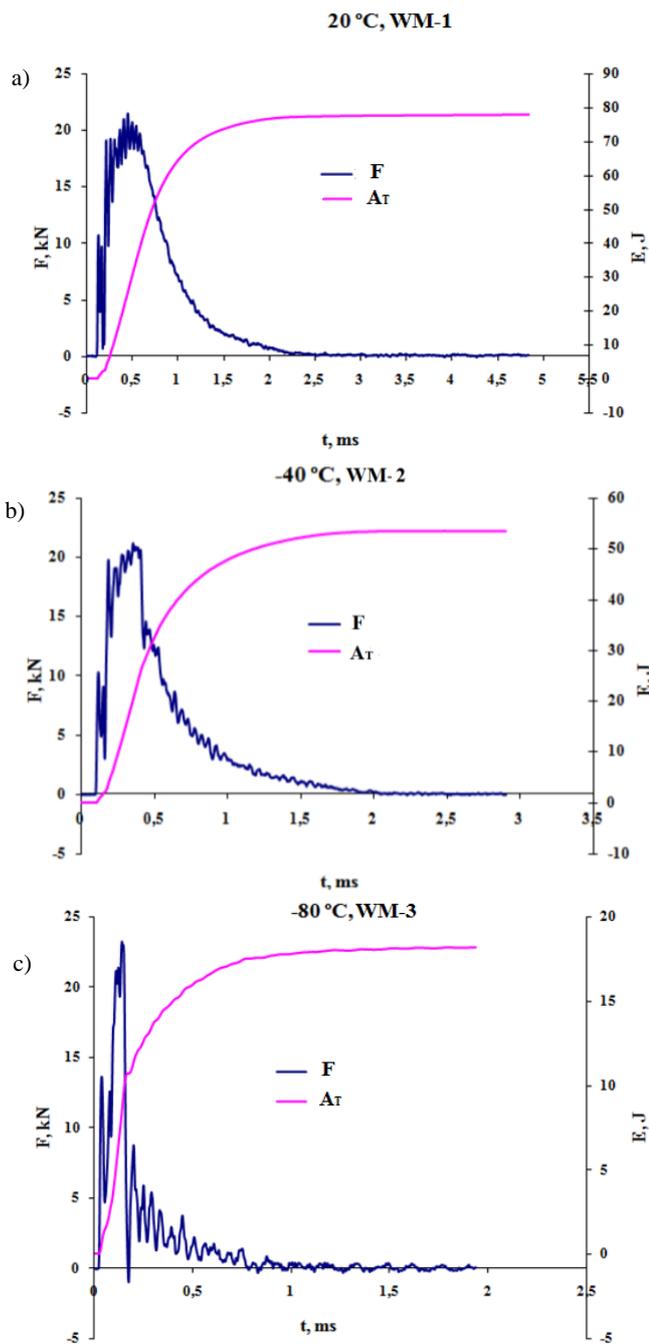


Figure 5. Diagrams force-time and energy-time for WM at 20 °C, -40 °C and -80 °C (a, b, and c).

Results from the diagram are given in the following tables /10/. More precisely, impact toughness results for parent metal specimens are in Table 2. For weld metal of NN-70, impact toughness results are in Table 3. Impact toughness results for heat-affected zone of NN-70 are in Table 4, with a note that only some of the test results are given in this paper.

Table 2. Total and crack initiation and propagation energies - PM.

Spec.	Temp. (°C)	A _T (J)	A _I (J)	A _P (J)
PM-1	20	97.08	39.07	57.90
PM-2	-20	96.89	41.59	55.30
PM-3	-60	60.78	41.44	19.34
PM-4	-100	52.91	46.21	6.7

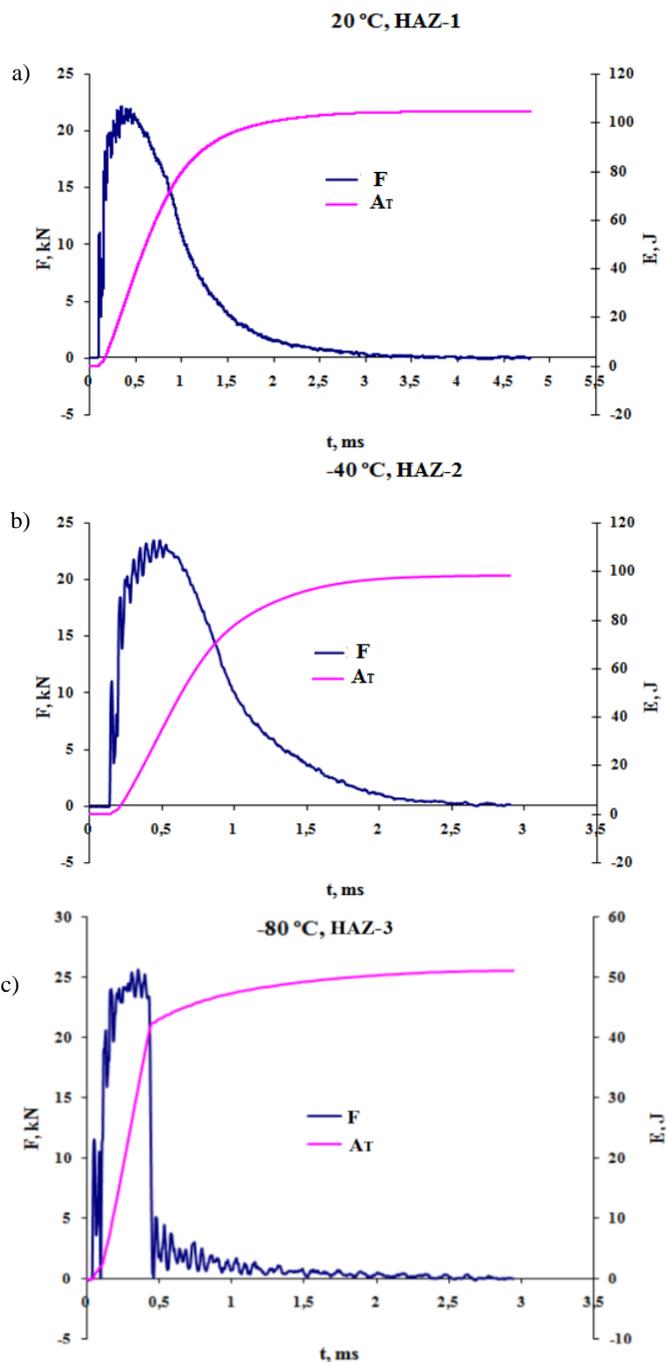


Figure 6. Diagrams force-time and energy-time for HAZ at 20 °C, -40 °C and -80 °C (a, b, and c).

Table 3. Total and crack initiation and propagation energies -WM.

Spec.	Temp. (°C)	A _T (J)	A _I (J)	A _P (J)
WM-1	20	78.24	24.60	53.64
WM-2	-40	53.69	21.85	31.85
WM-3	-80	18.28	8.21	10.07

Table 4. Total and crack initiation and propagation energies -HAZ.

Spec.	Temp. (°C)	A _T (J)	A _I (J)	A _P (J)
HAZ-1	20	104.88	26.80	78.09
HAZ-2	-40	98.59	32.58	66.01
HAZ-3	-80	51.34	27.99	23.35

CONCLUSION

By analysing the diagrams force-time and energy-time for parent metal at 20 °C, -20 °C, -60 °C and -100 °C, given in Fig. 4, as well as the values in Table 2, it is observed that the total impact energy for parent metal at 20 °C and -20 °C is approximately the same and higher than the total impact energy for parent metal at -60 °C and -100 °C. In the case of parent metal crack initiation energy at the mentioned test temperatures, they are approximately the same values and range from 37 to 46 J, while in the case of crack propagation energy, the values of parent metal at 20 °C and -20 °C are approximately the same and higher from parent metal values at -60 °C and -100 °C.

Analysing diagrams force-time and energy-time for weld metal at 20 °C, -40 °C and -80 °C, given in Fig. 5, as well as the values read in Table 3., it is observed that the total impact energy for weld metal at 20 °C is higher than the total impact energy for weld metal at -40 °C and -80 °C. In the case of weld metal crack initiation energy and crack propagation energy at 20 °C, a higher value is observed compared to the values of weld metal at -40 °C and -80 °C.

At the heat affected zone of NN-70, as a remaining constituent of the welded joint, analysing diagrams force-time and energy-time for heat affected zone at 20 °C, -40 °C and -80 °C, given in Fig. 6, as well as the values read in Table 4, it is observed that the total impact energy for heat affected zone at 20 °C is slightly higher than the total impact energy at -40 °C as well as evidently larger at -80 °C. In the case of heat affected zone crack initiation energy the highest value is observed at -40 °C while the highest values for crack propagation energy are observed at 20 °C.

From the above analysis of the impact tests, the conclusion clearly emerges that at 20 °C (PM, WM and HAZ) the results of total energy and propagation energy are the highest, which confirms the already well-known fact that toughness is lower at lower temperature.

The biggest influence on the total impact energy and its components has the test temperature on impact toughness, because it is closely related to the plastic properties of the tested high strength low-alloy steel. From the conducted tests, it can be seen that lowering the test temperature leads to creation of brittle fracture in the form of a successive decrease in the total impact energy from 20 to -100 °C for PM and from 20 to -80 °C for WM and HAZ. Also, from the tests in this paper, for all constituents (PM, WM and HAZ), it can be seen that the total impact energy depends on the notch position in specimens.

It should be noted that the selected welding technology also played an important role, which was reflected in the selection of additional welding material in this case of the EVB 75 electrode. Also, preheating of 170 °C significantly improved the toughness of the material, primarily in the HAZ as the critical zone of the welded joint, which automatically meant better impact properties.

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