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STRESS CONCENTRATION EFFECTS ON TOUGHNESS VALUE OF DUPLEX STEEL S32750

UTICAJ KONCENTRACIJE NAPONA NA VREDNOST ŽILAVOSTI DUPLEKS ČELIKA S32750

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Keywords
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- impact testing
- fatigue crack growth
- crack sensitivity factor

Ključne reči
- dupleks čelik S32750
- udarno ispitivanje
- rast zamorne prsline
- faktor osetljivosti prsline

Abstract

The paper presents the effect of stress concentration on duplex steel S32750 (according to UNS standards or W.Nr. 1.4410 according to EN standards) behaviour under impact loading. This analysis is based on the results obtained by experimental testing, with particular focus on the influence of crack-like defects on material behaviour under impact load.

Izvod

Predmet rada je analiza uticaja koncentracije napona na ponašanje dupleks čelika S32750 (prema UNS standardu ili W.Nr. 1.4410 prema EN standard) pri udarnom opterećenju. Na osnovu dobijenih rezultata ispitivanja, analiziran je uticaj prisustva greške tipa prsline na ponašanje materijala predviđenog za udarno opterećenje.

INTRODUCTION

Input data related to structural material selection for application primarily includes properties which are obtained from tensile tests (yield stress, tensile strength, elongation). These properties provide a global description of material behaviour obtained by testing of smooth specimens. Additional data about material behaviour can be obtained from impact tests, such as fracture energy for notched specimens, as shown in /1-5/. This energy represents local material behaviour, influenced by the presence of stress concentration. In the case of impact testing, the possibility of dividing total impact energy into crack initiation and propagation components introduced a new approach to material behaviour assessment, /2-5/.

The main goal of this paper is to use the so-called *Crack Sensitivity* method to adopt criteria for defect acceptability in the material and is based on performed impact tests of specimens. These results were used to analyse the effect of exploitation conditions on behaviour of duplex steels under impact loads. The significance of this research is particularly important when considering the current trend of revitalisation of many important structures and their vital components, especially those working under impact loads.

MATERIAL

Effects of temperature on impact properties in the presence of cracks and its integrity assessment under variable loads was investigated for a high-alloy Super Duplex steel S32750 (W. 1.4410). Standard specimens were used, Fig. 1. Data for mechanical properties and composition of this material are given in Tables 1 and 2.

Figure 1. Delivered specimens of Super Duplex grade S32750.

Table 1. Chemical composition of Super Duplex steel S32750.

Element	%	Element	%	Element	%
C	0.02	Cu	0.1	W	0.036
Si	0.49	Al	0.0084	N	0.272
Mn	0.88	Sn	0.005	Co	0.1064
S	0.0003	Mo	3.61	Zr	0.0061
P	0.0236	V	0.044	B	0.0022
Cr	25.3	Ti	0.005	Pb	0.0007
Ni	6.85	Nb	0.0056	Ca	0.0018
Ta	0.01	Ce	0.0271		

Table 2. Mechanical properties of Super Duplex steel S32750.

Yield stress $R_{p0,2}$ (MPa)	Tensile strength R_m (MPa)	Elongation at failure A_5 (%)	Impact toughness KV, 20 °C (J)			Yield stress $R_{p0,1}$ (MPa)
584	855	32	301	298	294	712

EXPERIMENTAL TESTING

Impact tests

The bending test performed with impact loads on the notched specimens can provide detailed insight into material behaviour under constrained deformation, i.e., for three-dimensional stress state. Determining the work needed for failure under specific testing conditions is mostly used in the quality control and for determining the homogeneity of materials in exploitation and during treatment. This testing procedure can be used to determine the tendency towards brittle fracture, i.e., the tendency towards increased brittleness during exploitation (also known as ageing), /6/.

Notched specimens were tested in order to determine total impact energy. The test procedure, along with the shape and dimensions of the specimen and position of notch, are defined in accordance with the standard SRPS EN ISO 148-1:2017 Metallic materials - Charpy impact testing - Part 1: Test methods, /7/. Specimen geometry and sizes are depicted in Fig. 2.

During impact testing, fracture energy is determined as an integral quantity. Energy determined in this way cannot be divided into the crack initiation and the crack propagation energy. In order to achieve this, it is necessary to continually record the force and time during the test, which can be done using an instrumented Charpy pendulum. The instrumented method for impact testing is a result of application of state-of-the-art acquisition measuring methods, according to standard SRPS EN ISO 14556:2020 Metallic materials - testing of V-notched specimens with a Charpy pendulum - instrumented test method, /8/.

By performing tests using an instrumented pendulum, force-time and energy-time diagrams are obtained, which allow a more detailed analysis of results, mainly in the sense of assessing the effect of testing temperature on total impact energy E_{tot} and its components: crack initiation energy E_I, and crack propagation energy E_P, /2-5/. Impact testing of specimens made of super duplex steel plates were performed at 20 °C, -20 °C, -40 °C, -60 °C, -80 °C and -100 °C. Results of these tests are given in Table 3, indicating very high values of both crack initiation and propagation energies at room temperature and sufficient level of crack propagation and total impact energies even at -100 °C. Also, one can notice that crack propagation energy is significantly higher than crack initiation energy, at all tested temperatures.

Typical examples of force-time and energy-time plots are shown in Fig. 3, for different testing temperatures.

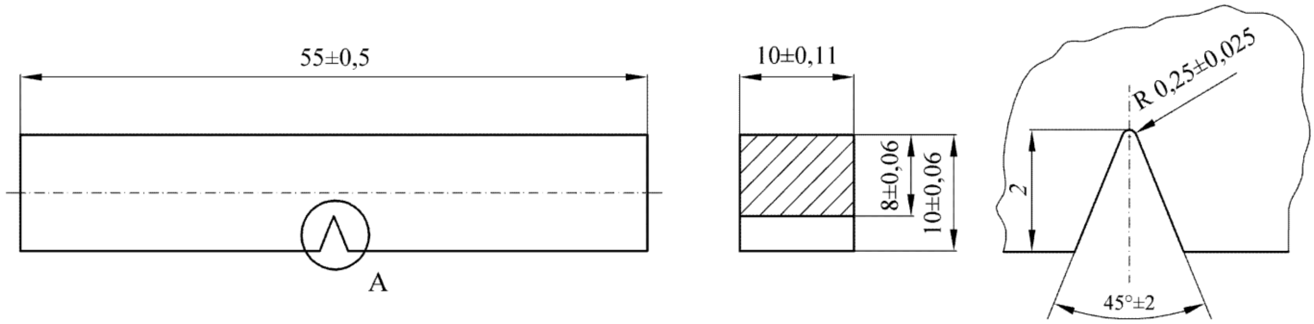

Figure 2. Shape and dimensions of the standard Charpy test specimen with a V-notch, /7/.

Table 3. Impact test results on specimens with V-2 notch.

Specimen designation	Temperature (°C)	Total impact energy E_{tot} (J)	Crack initiation energy E_I (J)	Crack propagation energy E_P (J)
BM_{-100} - 1	-100	46	11	35
BM_{-100} - 2		48	12	36
BM_{-100} - 3		35	10	25
BM_{-80} - 1	-80	88	18	70
BM_{-80} - 2		79	17	62
BM_{-80} - 3		79	17	62
BM_{-60} - 1	-60	122	25	97
BM_{-60} - 2		136	27	109
BM_{-60} - 3		116	24	92
BM_{-40} - 1	-40	193	45	148
BM_{-40} - 2		212	46	166
BM_{-40} - 3		199	45	154
BM_{-20} - 1	-20	253	56	197
BM_{-20} - 2		236	54	182
BM_{-20} - 3		245	54	191
BM_{20} - 1	20	298	53	245
BM_{20} - 2		300	52	248
BM_{20} - 3		294	52	242

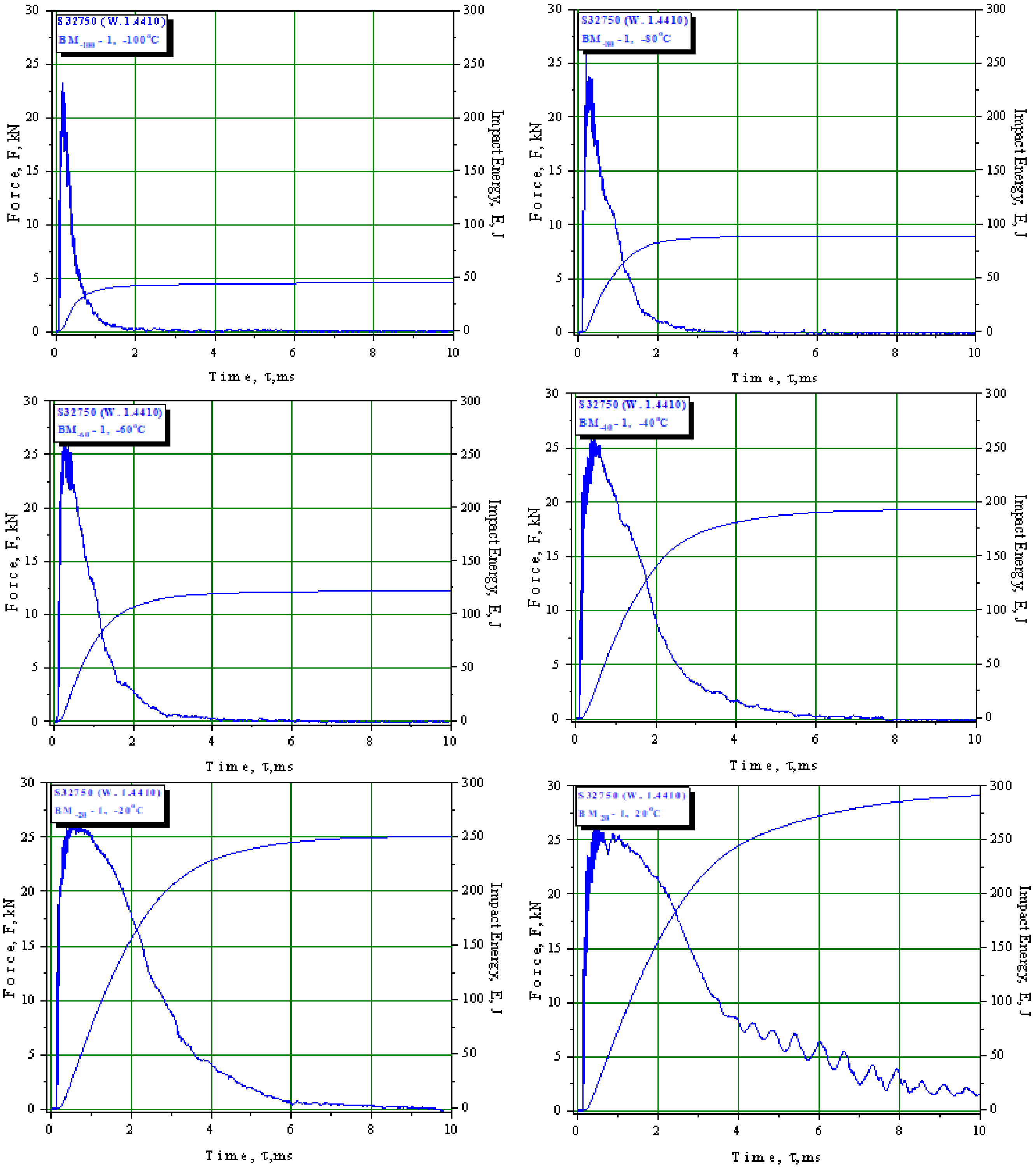

Figure 3. Force vs. time, and energy vs. time relationships, for base metal specimens.

Impact testing of cracked specimens

Crack sensitivity (CS) is determined by the ratio of total impact energy (KV value), obtained from a standard ISO-V specimen and KV1 value, obtained on a standard ISO-V specimen which contains a fatigue crack /8/:

$$CS = KV / KV1 . \tag{1}$$

Fatigue crack lengths ranged from 1 to 5 mm, measured from notch root on ISO-V specimens. Typical force-time and energy-time diagrams for different crack lengths are given in Fig. 4 for the following test temperatures: 20 °C, -40 °C, -60 °C, and -80 °C.

After failure, the fatigue crack length was measured at 5 locations, and its mean value, along with the corresponding KV (total energy), make up the pair of values in a KV-*a* diagram. Diagram origin is located at notch depth of 2 mm, for a standard notch depth of ISO-V specimen. Typical KV-*a* diagrams for high-alloyed super duplex steel S32750 tested at different temperatures are shown in Figs. 5 to 8.

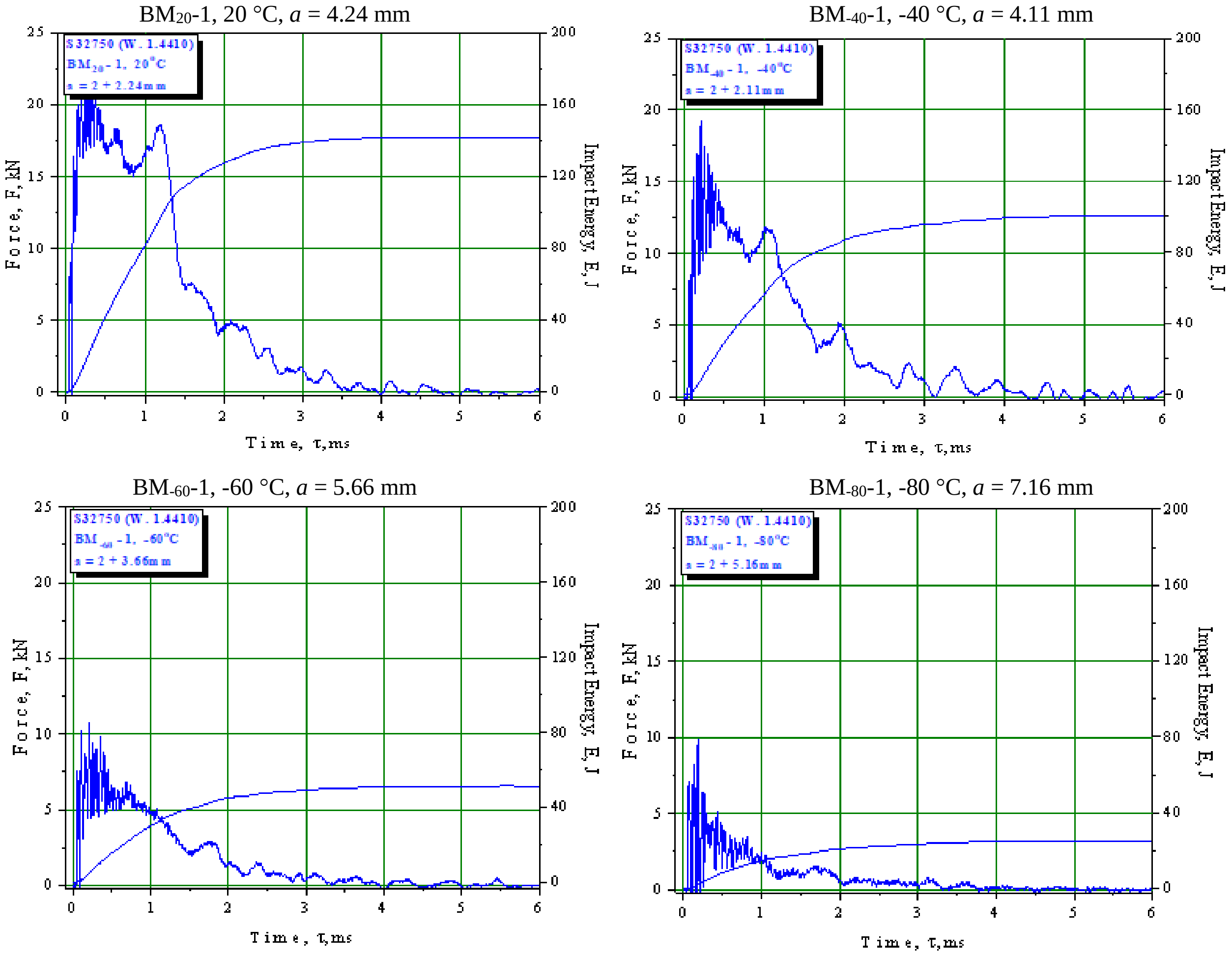

Figure 4. Force vs. time, and energy vs. time diagrams for the base metal specimen with a crack.

KV-*a* curves, shown in Figs. 5-8 for all combinations of temperatures, are defined using a second order polynomial. Based on these results, values for the crack sensitivity factor are calculated and presented in Table 4. As one can see, the crack sensitivity factor has a maximum at -40 °C. Anyhow, one should also note that values for crack sensitivity factor are relatively low, indicating high toughness of the material in general.

Table 4. Crack sensitivity factors for steel S32750.

Specimen type	Notched specimen KV	Cracked specimen KV1	Crack sensitivity KV/KV1
BM, 20°C	297	225	1.32
BM, -40°C	201	147	1.37
BM, -60°C	125	98	1.28
BM, -80°C	82	72	1.14

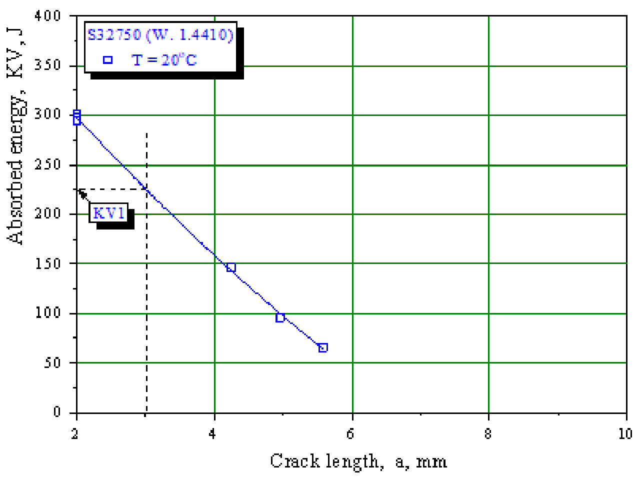

Figure 5. Impact energy KV vs. crack length *a*, for BM, 20 °C.

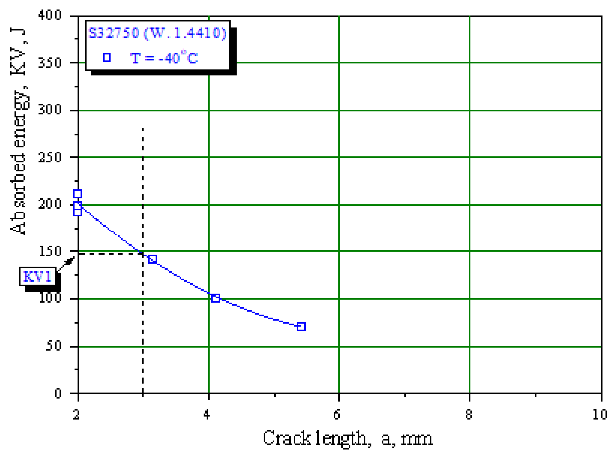

Figure 6. Impact energy KV vs. crack length *a*, for BM, -40 °C.

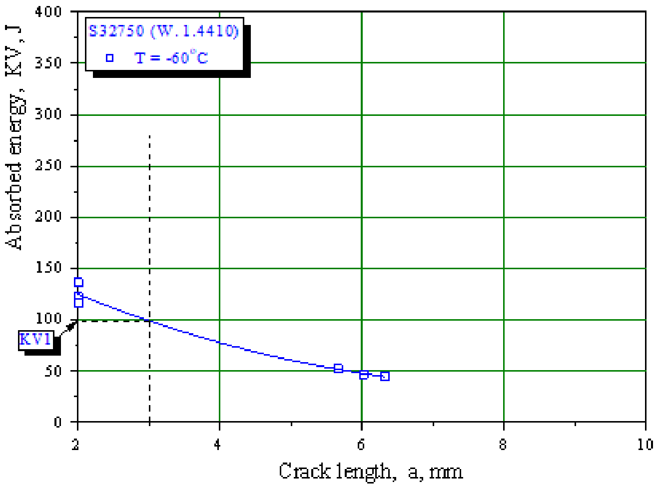

Figure 7. Impact energy KV vs. crack length *a*, for BM, -60 °C.

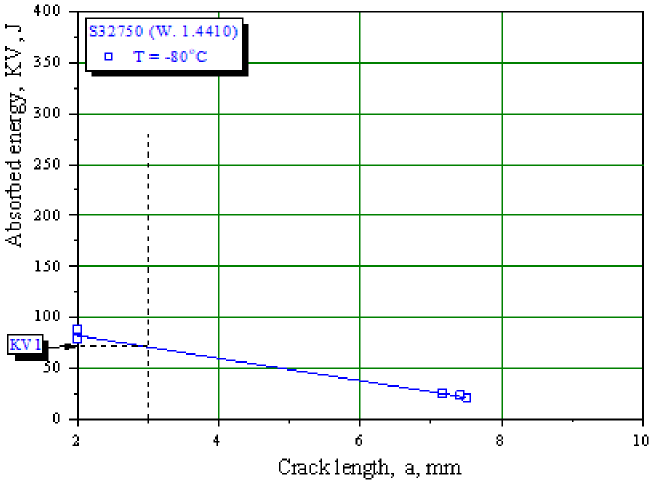

Figure 8. Impact energy KV vs. crack length *a*, for BM, -80 °C.

CONCLUSIONS

Based on presented results we conclude the following:

– duplex steel S32750 has a high total impact toughness at all tested temperatures, including -100 °C;

– at all testing temperatures the crack propagation energies are significantly higher than crack initiation energies, which is a favourable distribution of energies from the structural integrity point of view;

– crack sensitivity factor also indicates that duplex steel S32750 is a very tough material at all tested temperatures.

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