ISSN 1330-3651
UDC/UDK 625.143.2.042.2:620.17

IN-SERVICE DAMAGE OF RAILWAY STEEL AXLES

Oleh Yasniy, Tomaž Vuherer, Yuriy Pyndus, Andriy Sorochak, Ivan Samardžić

Preliminary notes

The influence of temperature and specimens undercut place on impact toughness of railway axle material in service is investigated. The obtained results show inversely proportional dependence of impact toughness on undercut radius of specimens. The decrease of test temperature from +20 to –40 ºC decreases significantly the impact toughness and portion of ductile fracture.

Key words: *impact toughness, in-service demage, railway axle, undercut*

Oštećenje na čeličnoj tračničkoj osovini u eksploataciji

Prethodno priopćenje

U radu je istražen utjecaj temperature i mjesta zajeda uzorka na udarnu žilavost materijala tračničke osovine u eksploataciji. Dobiveni rezultati pokazuju obrnutu proporcionalnost ovisnosti udarne žilavosti o polumjeru zajeda na uzorcima. Smanjenjem temperature ispitivanja od +20 to –40 ºC značajno se smanjuje udarna žilavost i udio žilavog loma.

Ključne riječi: *oštećenje u eksploataciji, tračnička osovina, udarna žilavost, zajeda*

1 Introduction
Uvod

During exploitation the railway axle is subjected to the static and cyclic loading, corrosive action and environment temperatures. The tendency to the brittle fracture of material can be described by means of impact toughness. In this paper the influence of temperature and the specimens' undercut radius on impact toughness of railway axle material is investigated.

2 Experimental technique
Eksperimentalna tehnika

Material of electric locomotive railway axle – the OSL steel – after 20 years of service was investigated. Since in the process of exploitation of railway axle fatigue cracks are initiated on its surface and grow in radial direction, specimens were cut in axial direction. Specimens for determination of impact toughness were cut out from an axle's section with diameter 198 mm at different distances from its center. The scheme of specimens cutting is shown in Fig. 1.

The impact toughness was determined on 10×10×55 mm Charpy specimens with V-notches, 0,25±0,025 mm in radius, that were tested by three-point bending. The RKP-300 type impact-testing machine with the impact energy of 300 kJ was used. Load-displacement diagrams in the coordinates "impact force versus time" and "impact force versus displacement of the specimen" were recorded. Two series of tests were done – under temperature of +20 °C and –40 °C. Using the obtained diagrams, the force at which plastic deformation begins, the total energy of fracture, the energy of crack initiation and energy of crack propagation were determined. The portion of ductile fracture was also assessed based on the results of fractography investigations of the specimens' fracture surface.

The impact toughness was calculated using the

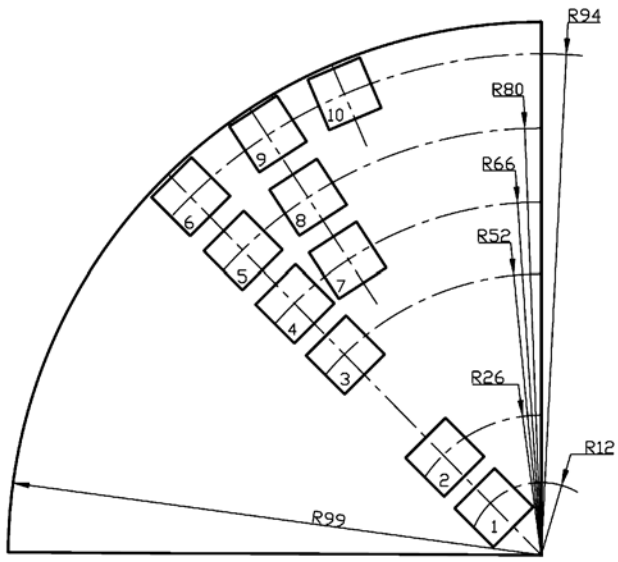

Figure 1 *The scheme of specimens cutting*
Slika 1. *Shema rezanja uzoraka*

formula:

$$KCV = \frac{E}{A} \tag{1}$$

where E – the total energy of fracture; A – cross-sectional area of specimen at V-notch place.

The control program of the RKP-300 testing machine and record program of test information "VUHI-CHARPY" allows to determine the value of constituents of specimen's fracture energy by converting the dependence "impact force versus time" (F–t) into dependence "impact force versus displacement" (F–s). The change of impact hammer speed $v(t)$ during loading of Charpy specimen with known mass of impact hammer m, initial velocity v_0 and dependence $F(t)$ was calculated using double successive integration according to recommendations [1, 2]:

$$\nu(t) = \nu_0 - \frac{1}{m}\int_{t_0}^{t} F(t)\mathrm{d}t. \tag{2}$$

In this case the dependence of impact hammer displacement s on time t can be found as:

$$s(t) = \int_{t_0}^{t} \nu(t)\mathrm{d}t. \tag{3}$$

The $F(s)$ dependence and portions of energy for fracture at partial stages were calculated using the above mentioned expressions.

The fractography investigations of the specimens' fracture surface were carried out on the scanning electron microscope Selmi REM-106I in the secondary electrons mode. The polished surface of specimens was etched in the mixture of hydrochloric and nitric acids, then washed in acetone and dried out.

3 Discussion
Rasprava

The railway axles are made of medium-carbon steel OSL [3], obtained by an open-hearth, basic oxygen or electroarc process. Chemical composition of steel meets the standards and is shown in Tab. 1.

Table 1 *Chemical composition of OSL steel (mass concentration of elements, in %)*
Tablica 1*. Kemijski sastav OSL čelika (masene koncentracije elemenata, u %)*

C	Mn	Si	P	S	Cr	Ni	Cu
			less than				
0,42-0,45	0,60-0,90	0,15-0,35	0,040	0,040	0,30	0,30	0,25

Load-displacement diagrams of specimens in coordinates "expense of energy on destruction versus time" can be seen in Fig. 2.

Results of experimental determination of impact toughness KCV for each specimen, total energy of fracture E, energy of crack initiation E_i and energy of crack propagation E_p are presented in Tab. 2.

The dependences of impact toughness on the undercut radius of specimens from the locomotive wheelpair axle are

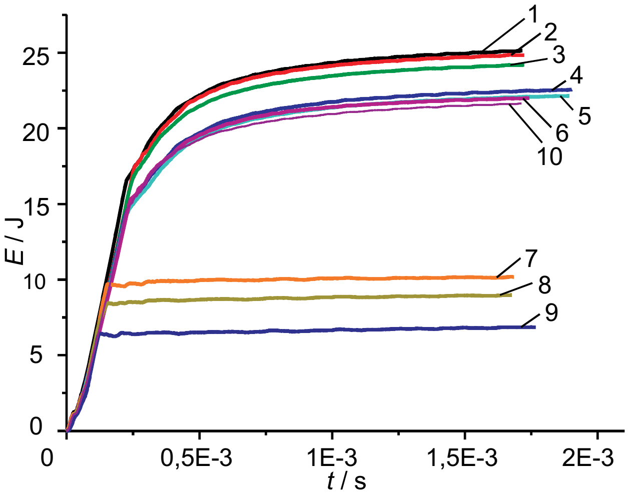

Figure 2 *Load-displacement diag. of specimens in coordinates, fracture energy versus time, at temperature +20 °C (1-6, 10) and –40 °C (7-9)*
Slika 2. *Dijagram opterećenje-pomak uzoraka u koordinatama, energija loma u odnosu na vrijeme, pri temperaturi od +20 °C (1-6, 10) i –40 °C (7-9)*

inversely proportional (Fig. 3). Particularly, with the increase of undercut radius from 12 mm to 94 mm the impact toughness decreases to 15,6 % at temperature +20 ºC, and with the change of undercut radius from 66 mm to 94 mm at –40 ºC this parameter decreases to 32,5 %. The reasons of this phenomenon can be in the technology of producing railway axles, during which an axle is subjected to the strengthening treatment by a roller on a full length for the increase of high-cycle fatigue resistance [4].

The decrease of test temperature from +20 to –40 °C decreases significantly the impact toughness and portion of ductile fracture. For the subsurface layers of axle impact toughness decreases by more than 3 times.

The microstructure of OSL steel is depicted in Fig. 4. This steel belongs to ferrite-pearlite class of materials. The presence of structurally free ferrit and pearlite colonies that are located in different parts of ferrite grains was found by scanning electron microscope researches. On the basis of SEM image analysis it was determined that ferrite grains occupy about 30 % of the observed specimen area. Their average size is about 10 μm. The average size of pearlite colonies is 25 μm and the minimum pearlite interlamellar spacing is 0,2 μm. This value of interlamellar spacing is typical for sorbite microstructure.

Table 2 *Results of experimental determination of impact toughness*
Tablica 2. *Rezultati eksperimentalnog određivanja udarne žilavosti*

Sp. No.*	Undercut radius, mm	Test temperature, ºC	E_i/J	E_p/J	E/J	Portion of ductile fracture, %	KCV/J/cm^2
1	12	+20	15,8	9,3	25,2	28,1	32,0
2	26	+20	16,3	8,6	24,9	33,1	31,1
3	52	+20	15,0	9,2	24,2	31,9	30,3
4	66	+20	13,6	9,0	22,6	33,0	28,2
5	80	+20	13,6	8,5	22,1	21,1	27,7
6	94	+20	13,4	8,6	22,0	26,6	27,5
7	66	–40	8,1	2,1	10,2	4,1	12,7
8	80	–40	5,2	3,8	9,0	3,3	11,2
9	94	–40	4,2	2,7	6,9	5,1	8,6
10	94	+20	13,6	8,1	21,7	33,3	27,1

Sp. No. – Specimen number*

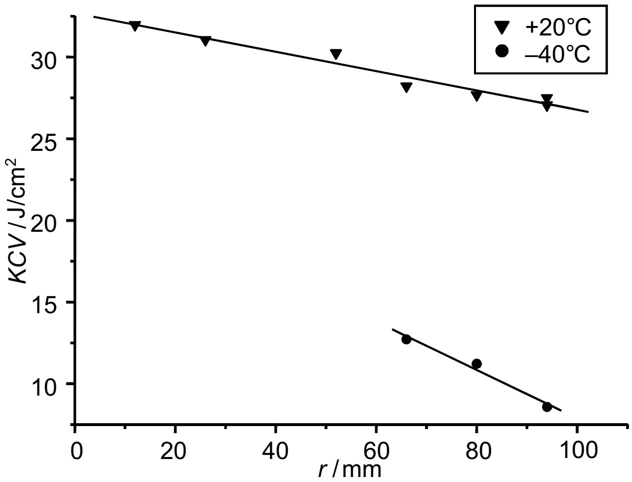

Figure 3 *Dependence of impact toughness on the undercut radius of specimens*
Slika 3. *Ovisnost udarne žilavosti o radijusu podreza uzoraka*

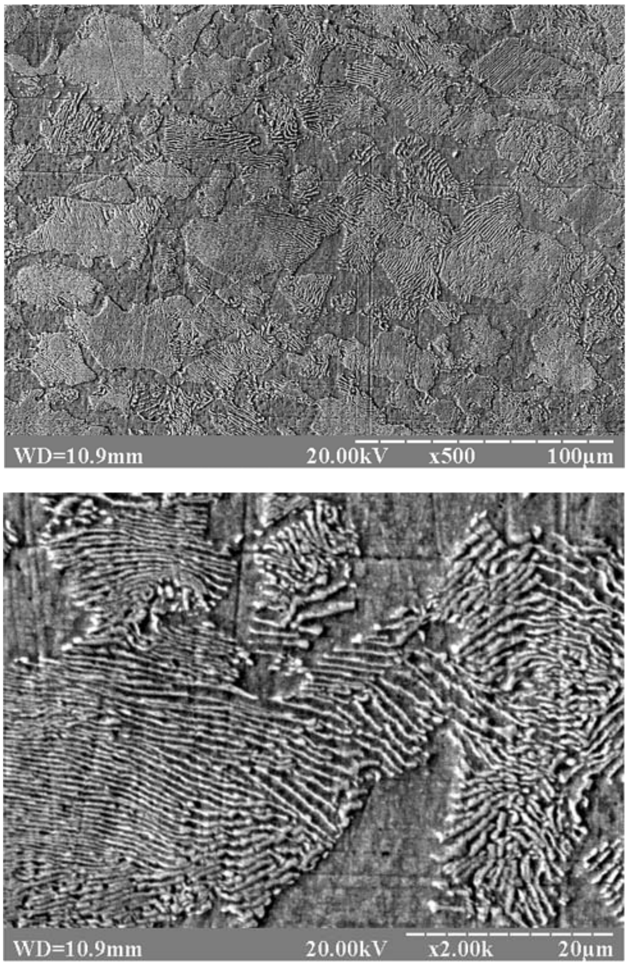

Figure 4 *Microstructure of the OSL steel*
Slika 4. *Mikrostruktura OSL čelika*

Fracture surface of OSL steel at temperature +20 °C (Fig. 5a) consists of successive areas of dimple ductile transgranular fracture (Fig. 5b) and areas of cleavage (Fig. 5c). The fracture is characterized by an insignificant plastic strain, the fracture surface is formed by a net of combs, that indicates the presence of brittle and separate ductile micromechanisms of destruction [5]. With the decrease of test temperature to –40 °C the portion of ductile fracture is reduced to 3-5 %.

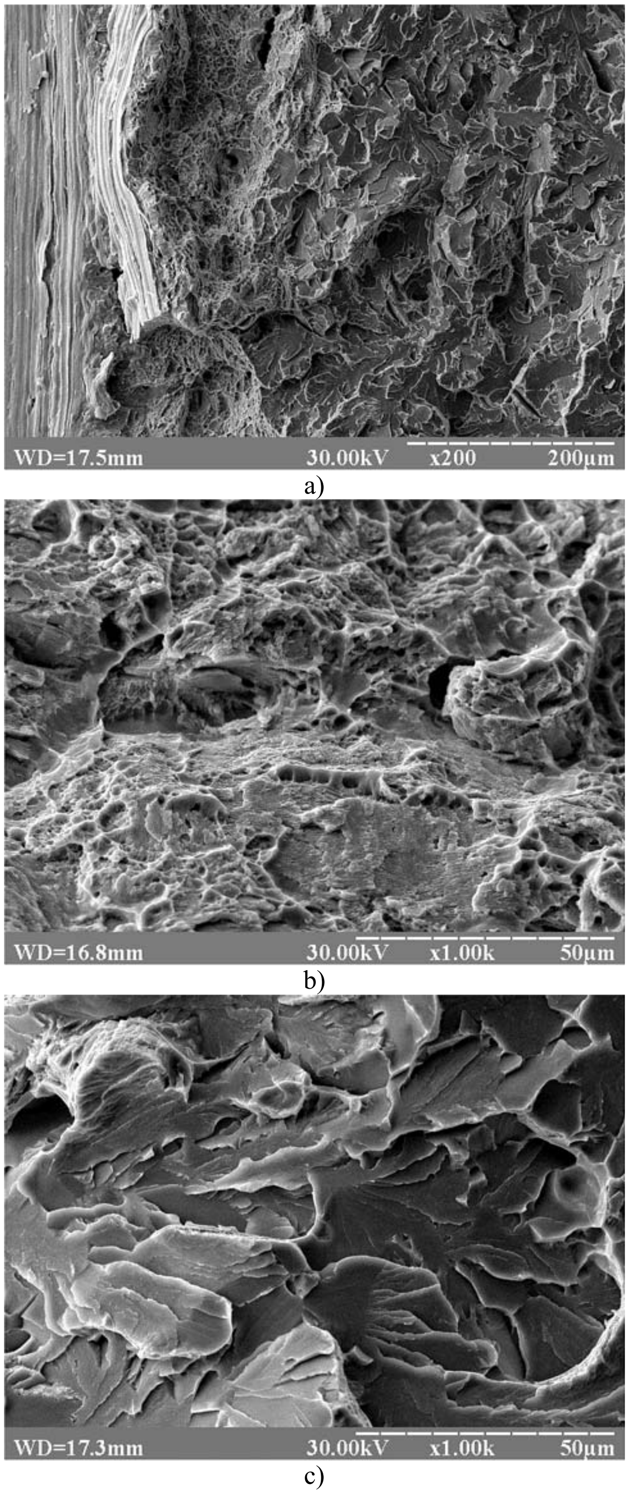

Figure 5 *Fracture surface of Charpy specimen (a) and areas of ductile fracture (b) and cleavage (c)*
Slika 5. *Površina loma Charpyevog uzorka (a) i područje duktilnog loma (b) i rascjepa (c)*

4 Conclusions
Zaključci

The influence of temperature and undercut radius of specimens on impact toughness of the material of railway axle is investigated. It was determined that with the increase of undercut radius of specimen from the axle, impact toughness decreases linearly. Decreasing of test temperature from +20 °C to –40 °C results in decreasing of impact toughness by 3 times.

Scanning electron microscopy investigation shows that the material of locomotive axle – the OSL steel – belongs to ferrite-pearlite class of materials. Fractography study of fracture surfaces of specimens shows the presence of successive areas of dimple ductile fracture and areas of cleavage. With the decrease of test temperature to –40 ºC the portion of ductile fracture is considerably reduced.

Acknowledgments
Zahvale

The authors acknowledge the support of common Ukrainian-Slovenian project under the number of state registration of Ukraine 0109U005184.

5 References
Literatura

[1] ISO 14556. Steel Charpy V-Notch Pendulum Impact Test – Instrumented Test Method. – 05.01.2005.
[2] Kharchenko, V. V.; Kondryakov, E. A.; Zhmaka, V. N. Influence of temperature and loading rate on energy of crack initiation and crack propagation of Charpy specimens from carbon steel // Strength of materials. 5 (2006), str. 120-127. (in Russian).
[3] GOST 4728-96. Axle billets for 1520 mm gauge railway rolling stock. Specifications. – 1997. (in Russian).
[4] GOST 30272-96. Black collar axles (profile stock) for 1520 mm gauge railways. Specifications. – 1997. (in Russian).
[5] Strnadel, B.; Haušild, P. Statistical scatter in fracture toughness and Charpy impact energy of pearlitic steel // Material science and engineering. 486, 1-2(2008), str 208-214.

Authors' addresses
Adrese autora

Oleh Yasniy
Ternopil Ivan Pul'uj State Technical University
Ruska Str. 56
46001 Ternopil, Ukraine
e-mail: oljgen@gmail.com

Tomaž Vuherer
University of Maribor
Faculty of Mechanical Engineering
Slovenia
e-mail: vuhi38@gmail.com

Yuriy Pyndus
Ternopil Ivan Pul'uj State Technical University
Ruska Str. 56
46001 Ternopil, Ukraine

Andriy Sorochak
Ternopil Ivan Pul'uj State Technical University
Ruska Str. 56
46001 Ternopil, Ukraine

Ivan Samardžić
Mechanical Engineering Faculty in Slavonski Brod
J. J. Strossmayer University of Osijek
Trg Ivane Brlić-Mažuranić 2
35000 Slavonski Brod, Croatia