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# AN INCREASE OF IMPACT TOUGHNESS OF LOW-CARBON STEEL CAUSED BY IMPULSE ELECTRIC CURRENT TREATMENT

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Investigation results indicating the influence of high-density impulse electric current on impact toughness of Charpy specimens manufactured from low carbon steel are presented. It is shown, that impulse electric current treatment causes a considerable growth of impact toughness of the steel, and type of material fracture is changed from brittle mode to ductile mode.

***Key words:*** *low-carbon steel, impact toughness of Charpy, impulse electric current*

**Povećanje otpornosti na udar nisko-ugljičnog čelika uzrokovan obradom pulsnom strujom.** Prikazani su rezultati istraživanja koji pokazuju utjecaj pulsne struje visoke gustoće na otpornost na udar uzoraka Charpy proizvedenih iz nisko-ugljičnog čelika. Prikazano je da obrada pulsnom strujom uzrokuje znatno povećanje tvrdoće čelika, i vrsta pucanja materijala je promijenjena iz lomljivog/krhkog oblika u rastezljivi/savitljivi oblik.

***Ključne riječi:*** *nisko-ugljični čelik, Charpy žilavost, pulsna struja*

## INTRODUCTION

It is well known from Russian-language literature that direct passage of high-density impulse electric current (IEC) causes an increase of some mechanical properties of structure metals. For example, substantial increase of strength (yield and ultimate stresses) also as plasticity of aluminium and titanium alloys and steels due to IEC treatment follows from [1 - 4]. At the same time, data about IEC influence on impact toughness of metals is limited. As it follows from [2], IEC treatment of aluminium alloys causes an increase of impact toughness on 40…50 %. It is also known that passage of IEC of high density through high-carbon steel specimens affects on crack initiation and propagation under impact bending [5]: crack initiation energy was increased in 2,5 times and crack propagation energy was increased in 2 times. In western journals the data about changes of mechanical properties of metals under above treatment are absent.

In the current paper the results of investigations of IEC influence on impact toughness of low-carbon steel under tests using conventional pendulum impact testing machine and instrumented vertical impact testing machine as well as some results of metallographic investigations are presented.

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## EXPERIMENTAL PROCEDURE

Standard Charpy specimens with 10 mm × 10 mm × 55 mm sizes and V-notched on 2 mm depth in the central part, made from St3 low carbon steel and with the length oriented longitudinally to rolling were used at the fulfillment of these researches. Part of the billets for specimens were treated by IEC according to the scheme described in [6], with the treatment regimes similar to used in the work [5], then they were V-notched.

Impact bending tests of the specimens were fulfilled at room temperature using KM-30 pendulum impact testing machine (loading velocity was 5 m/s) and vertical impact testing machine for instrumented Charpy tests (loading velocity was 4,4 m/s). Microstructure and fractures surfaces of the specimens in initial condition and after IECT were studied using optical microscope Axiovert 200 and SEM ZEISS ULTRA 55. Metallographic sections were made by standard method.

At the beginning, two sets of specimens (in initial / “as received” state and after IECT) in six in the each set were tested using pendulum impact machine. Whereupon, taking into account the dramatic effects of IECT, additional 54 specimens in the initial state were tested. Test results are presented in the table, they testify very strong influence of the IECT on metal impact toughness: power-consuming at the fracture after the treatment grew practically in 5 times. At the same time results of microstructure investigations of the steel in the initial state and after IECT executed using optical microscope specify that kind, sizes of grains and their form remain unchanged (see the table). Only in the longitudinal cuts of the specimens treated by IEC (in regions near to the break) grains are extended. It testifies noticeable plastic deformation of treated material.

Test results for specimens in initial and treated state obtained by use of instrumented vertical impact testing machine are presented on Figure 1. Registration data specifies on the of principle difference in fracture mechanisms: specimens in the initial state are failed in the brittle mode by crack skip (sharp load fall on Figure 1.a), at the same time the specimens after IECT are fractured with greater energy absorption, in the ductile mode. Similar conclusions come from the analysis of specimen fractures (Figure 2.). All 60 specimens in the initial state were fractured in the brittle mode, practically without any tough component and deformation markings in the fractures. Surfaces of failure in the specimens treated by IEC are absolutely differ: they have tough and fibrous fractures with strongly expressed plastic deformation; so-called «shear lips» occupy near the third of fracture area; part of tough component in the fracture surface is reached to 100 % in some specimens.

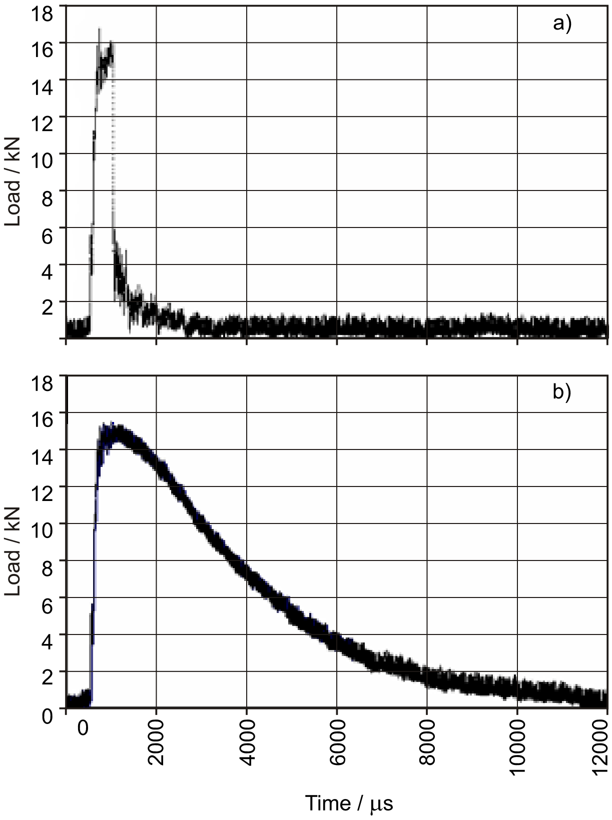


Figure 1. **Load-time diagrams from the impact bending tests: a) metal in initial state, b) metal after IECT**

Slika 1. **Dijagrami vremena opterećenja iz testova savijanja uslijed udara: a) metal u početnom stanju, b) metal nakon IECT-a**

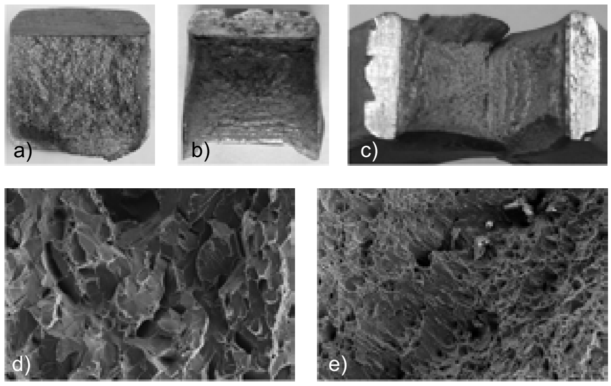


Figure 2. **Specimen fracture modes and surface fractography: a), d) metal in initial condition; b), c), e) metal after IECT; d), e) - 1000×**

Slika 2. **Oblici pukotine uzorka i fraktografija površine: a), d) metal u početnom stanju; b), c), e) metal nakon IECT-a; d), e) - 1000×**

The increase of impact toughness of St3 steel after IECT obtained under fulfillment of this work can not be explained by speed heat treatment, firstly because low content of carbon (0,14…0,22 %), and secondly because of low heating temperature (tens degrees) reached at the used treatment. It can be confirmed by hardness measurements fulfilled using COMPUTEST SC tester. Hardness data for metal, in initial state and after IECT presented on Figure 3. They testify the absence of the influence of used IECT on the level of specimens' hardness: in the both cases the middle hardness are approximately 80 HRB.

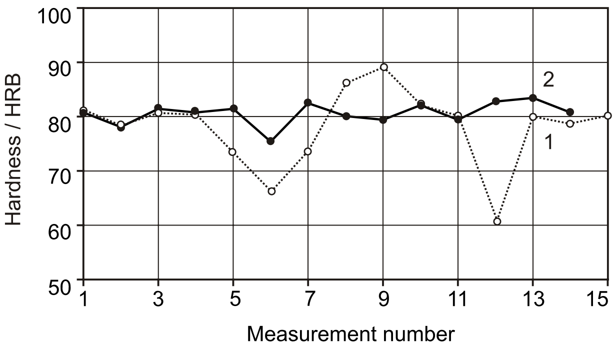


Figure 3. **Hardness distribution on specimen cross-section: 1 - metal in initial state; 2 - metal after IECT**

Slika 3. **Raspored tvrdoće na presjeku uzorka: 1 - metal u početnom stanju; 2 - metal nakon IECT-a**

According to the existing conceptions, the main reasons for brittle fracture of metals and alloys are microcracks, which appear in the process of plastic deformation under loading. This is specified by heterogeneity of micro-plastic deformations in the polycrystalline structure [7]. Deformation mismatch in the grains (phases) is a source for powerful fields of micro-stresses, which are sufficient for micro-crack origination in the polycrystalline materials. Concerning to the IECT influence on the metals, it is known that defects of different types in the crystalline structure (dislocations, point defects, grain borders, subgrains, micro-cracks, etc.) are the objects for increased action of electron wind. Hence, there is a dispersion of energy of electrons on them (its transition into thermal energy) under IECT. It causes the localized heating of metal micro-volumes nearby defects and their changes (increase of mobility, change of their density, etc.) [3, 8 - 11]. As a result, conditions for development of micro-plastic deformations (localized plastic micro-displacements) near defects are created. Above plastic micro-deformations cause the relaxation of micro-stress fields around the defects. On the macro-level it is appeared in the homogenization of some properties, for example, local deformability. This fact is confirmed by the results of hardness measurements, see Figure 3.: it is visibly that after IECT the hardness smoothing in the metal is observed.

## CONCLUSION

The increase of impact toughness for low-carbon steel obtained during fulfillment of these researches can be attributed to the increase of deformation homogeneity on grain borders (subborders). IECT causes decrease the intensity of micro-stress fields, consequently micro-cracks do not arise on the early stages of loading. As a result, whole volume of metal is involved in the deformation process that promotes power-consuming at the fracture. More precise definition of the mechanism of IECT influence on metal strength and fracture resistance is the task for further investigations.

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