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Original article

High strength low-alloy steels impact toughness assessment at different test temperatures

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ABSTRACT

In many production processes, as well as in the exploitation of machine components and structures, materials are exposed to impact loads. In structures made of welded joints of high strength low-alloy steels with their constituents (parent metal, weld metal and heat-affected-zone), the toughness test determines the tendency of steel to brittle fracture, respectively the tendency to increase brittleness during exploitation.
The strain rate is high and the material manifests much more brittle behavior than is shown by tensile testing. Toughness as a mechanical property is an important factor that is defined as the energy that needs to be spent in order to achieve fracture. Parameters obtained by testing the properties of plasticity are the basis for the design of structures in order to achieve strengths under applied load.
The test results of high strength low-alloy steel toughness assessment at different test temperatures show that temperature significantly affects the impact toughness of steels and their alloys. At higher temperatures the impact energy on fracture is high (the material shows the properties of plasticity) while at lower temperatures the impact energy is small (the material is brittle).

Key words: *impact toughness, high strength low-alloy steel, welded joint;*

1. INTRODUCTION

High-strength low-alloy (HSLA) steels or micro-alloyed steels are widely used structural steels for manufacturing of structures used in many industry branches such as process industry, shipbuilding and offshore structures, automotive industry, etc.
For many applications, the most important factor in the steel selection process is the favorable strength-to-weight ratio of HSLA steels compared with conventional low-carbon steels.
For steel structures such as pressure vessels, ship constructions, transport vehicles and so on, the most common manufacturing process is welding. That is why HSLA steels, besides high strength, should also have good plasticity, sufficient toughness and high resistance to brittle fracture, satisfactory workability and good weldability [1]. The capability of forming is another substantial material property, and for HSLA steels the weldability is of particular significance. Since requirements for safe service are more and more strict, the testing of ductility and toughness parameters is specified, including fracture resistance tests. All cited parameters are tested for the entire welded joint as well as for three joint constituents, parent metal (PM), weld metal (WM) and the heat-affected-zone (HAZ), since the requirement for service safety of welded structures, produced of HSLA steel has importance because of the consequences of eventual failure [2].

2. IMPACT TESTING OF HSLA STEEL

A large number of machine parts and structural parts are submitted to variable loads during exploitation. Properties of base material and especially welded joint that are submitted to impact load differ from the properties obtained in case of static force effect. Therefore, the need to determine them is understandable. Pre-cracked

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specimen testing by bending, performed by impact effect of force, can offer an explanation on the material behaviour in case of obstructed deformation, or three-dimensional stress state. Determination of the work needed for fracture, under certain test conditions, is most commonly used for the ongoing quality, material homogeneity and treatment control. Brittle fracture tendency and accordingly the brittleness increase during exploitation can be determined by this procedure [3].

The material used in the current experimental study was welded joint of high strength low-alloy steel (HSLA) Nionikral-70 (NN-70), designed for ship structures and pressure vessels.

The technology of manufacture and thermomechanical processing, of Nionikral-70 steel is the result of joint research from the Military Technical Institute in Žarkovo (VTI) and ironworks Jesenice from Jesenice, in the early 1990s. Steel is produced in the electric furnace, cast in plates, subsequently rolled into slabs and then into sheets of various thickness. Due to some of its characteristics, it is classified among fine-grained steels.

The process of hardening is the combination of classical improvement (quenching and tempering) with grain refinement in accordance with selected chemical composition, by microalloying and appropriate deposition [4, 5]. The chemical composition of NN-70 is given in Table 1.

Table 1 *Chemical composition of NN-70 (% wt)*

NN-70						
C	Si	Mn	P	S	Cr	Ni
0.106	0.209	0.220	0.005	0.017	1.258	2.361

Mechanical properties Nionikral-70 (NN-70) of welded joint are given in Table 2.

Table 2 *Mechanical properties of NN-70*

Yield strength (MPa)	***Ultimate strength (MPa)***	***Elongation (%)***
645	914	22.4

The specimens used in this experiment are standard Charpy specimens of rectangular cross section, with grinded and polished faces, taken from shielded manual arc butt welded 20 mm thick plates. Specimen dimensions are: length L=55 mm, width W=10 mm and thickness B=10 mm, with 2 mm deep notch, Fig. 1.

Impact tests of Charpy specimens with notches in parent metal, weld metal and the heat affected zone are performed in order to determine the total impact energy and its components - crack initiation and crack propagation energy.

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 [6-9].

Impact testing is performed on the SCHENCK TREBEL 150-300 J (Fig. 2), instrumented Charpy pendulum, at different temperatures (20 °C, -20 °C, -60 °C and -100 °C). The position of notch is according to EN 875 [10].

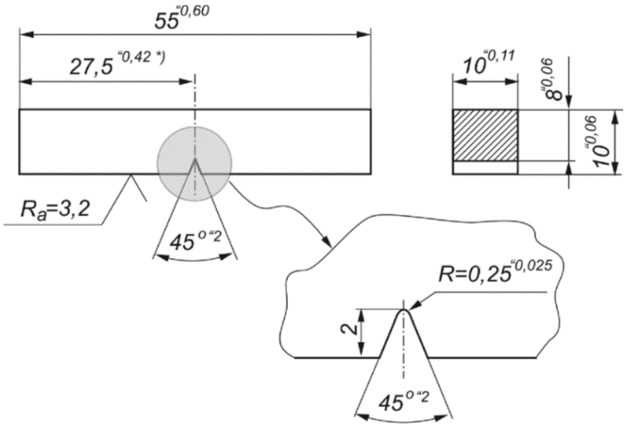

Fig. 1 *Charpy specimen for impact energy testing*

Fig. 2. *SCHENCK TREBEL for impact testing*

By testing the specimen with a notch on the instrumented Charpy pendulum, it is possible to obtain a force-time diagram (Fig. 3).

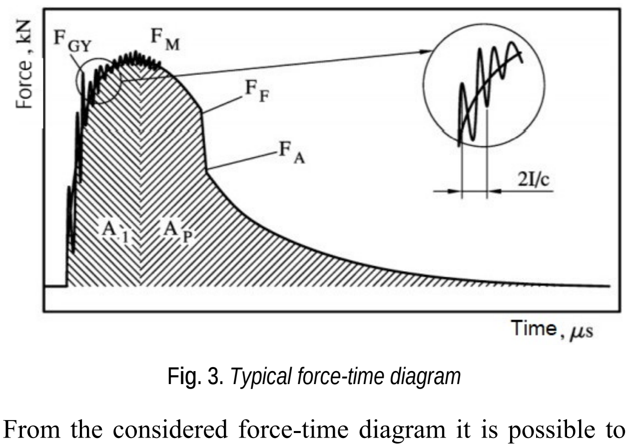

Fig. 3. *Typical force-time diagram*

From the considered force-time diagram it is possible to calculate the impact total energy required for the specimen fracture. The total impact energy is broken down into the part of crack initiation energy AI and the part of crack propagation energy AP. Areas AI and AP, on the force-time diagram, Fig. 3, are proportional to crack initiation and propagation energies.

Examples of results from impact toughness testing are given in Table 3 for specimens with notch in parent metal of NN-70, in Table 4 for specimens with notch in weld metal NN-70 and in Table 5 for specimens with notch in heat-affected zone NN-70. More precisely, testing is performed for parent metal at 20 °C, -20 °C, -60 °C and -100 °C. For specimens with notch in weld metal and heat-affected zone, testing is performed at 20 °C, -40 °C and -80 °C temperatures. Results that refer to a few of tested specimens are shown in Tables 3-5.

Table 3 *Impact test results for specimens with notch in parent metal (PM) of NN-70*

Spec.	***Test temper. °C***	***Total impact energy, AT (J)***	***Crack initiation energy, AI (J)***	***Crack propagation energy, AP (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

Table 4 *Impact test results for specimens with notch in weld metal (WM) of NN-70*

Spec.	***Test temper. °C***	***Total impact energy, AT (J)***	***Crack initiation energy, AI (J)***	***Crack propagation energy, AP (J)***
WM-1	20	78.24	24.60	53.64
WM-2	-40	53.69	21.85	31.85
WM-3	-80	18.28	0	18.28

Table 5 *Impact test results for specimens with notch in heat-affected zone (HAZ) of NN-70*

Spec.	***Test temper. °C***	***Total impact energy, AT (J)***	***Crack initiation energy, AI (J)***	***Crack propagation energy, AP (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

4. CONCLUSIONS

Comparing the values of force-time and energy-time for all three constituents of the welded joint (PM, WM and HAZ) of steel NN-70, it follows that the values of total impact energy and crack propagation energy are highest in tests at 20 °C, which means that as the temperature decreases, the toughness of the material decreases.

The location where specimens were taken has influence on the impact total energy value AT, as well as the V-notch position. Welded joint structure heterogeneity, followed by different mechanical properties of some areas in the welded joint (parent metal, weld metal and heat affected zone), has a crucial effect on impact properties, more precisely on the impact total energy value.

Thus, based on the obtained results of impact tests, it is clear that the total impact energy depends on:

- the location where specimens were taken (parent metal, weld metal and heat affected zone)
- test temperature

Therefore, it is obvious that a different microstructure in different regions of the welded joint NN-70 affects crack resistance more in dynamic than in static loading conditions. The test results of high strength low-alloy steel toughness assessment at different test temperatures show that temperature significantly affects the impact toughness of steels and their alloys. At higher temperatures the impact energy on fracture is high (the material shows the properties of plasticity) while at lower temperatures the impact energy is small (the material is brittle).

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NOTE

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