Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 42 (2022) 1475–1482

Structural Integrity Procedia

www.elsevier.com/locate/procedia

23 European Conference on Fracture - ECF23

Effect of temperature and specimen orientation on Charpy impact toughness

Bojana ZEČEVIĆ [1], Ana MAKSIMOVIĆ[1], Ljubica MILOVIĆ [2], Srđan BULATOVIĆ[3] and Vujadin ALEKSIĆ[3]

[1]*Innovation Centre of the Faculty of Technology and Metallurgy*, *4 Karnegijeva St, 11120 Belgrade, Serbia*
[2]*University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia*
[3]*Institute for Testing of Materials-IMS Institute, Belgrade, Serbia*

Abstract

Steel grade 14MoV6 3 is used for manufacturing of boilers and steam pipelines designed for steam temperatures up to 560°C. This paper presents the experimental analysis which included impact toughness test. The analysis resulted in impact energy values, and their respective components, crack initiation and crack propagation energy, and represents the initial stage of extensive research involving the behavior of 14MoV6 3 steel. The aim was to determine the effects of temperature (room vs. operated), as well as the effects of specimen orientation with regards to the rolling direction, on the impact toughness and the relation between its components.

Peer-review under responsibility of the scientific committee of the 23 European Conference on Fracture – ECF23

Keywords: Steam pipeline; Heat-resistant steels; Charpy impact test

1. Introduction

Fracture is defined as the separation of a material into two or more parts under the influence of stress. Fracture in majority of the cases is initiated by a small crack which develops into a major separation to cause failure. It therefore becomes very important to study the influence of the crack on the structural integrity.

*Corresponding author. Tel.: +387645523025; fax: +387113370387.
E-mail address: baleksic@tmf.bg.ac.rs

2452-3216
Peer-review under responsibility of the scientific committee of the 23 European Conference on Fracture – ECF23
10.1016/j.prostr.2022.12.188

Experimental analysis involved impact toughness tests. Impact toughness, obtained on the instrumented Charpy pendulum [1–3], giving as results the crack initiation energy value, the value of energy needed for the propagation of the crack, as well as the total crack energy. Those results can also be used as a comparative measure of crack resistance. Extensive information about similar tests carried out on creep-resistant materials and their behavior in terms of toughness and temperatures can be found in [4-6].

2. Material details

Steel grade 14MoV6-3 is classified as low-carbon steel micro-alloyed with chromium, molybdenum and vanadium. It is delivered in normalized and tempered condition. The chemical composition of the investigated material is given in Table 1.

Table 1. Chemical composition of as-received steel, %wt.

C	Si	Mn	P	S	Al	Cr	Mo	V
0.12	0.37	0.65	0.01	0.01	0.004	1.042	0.24	0.16

For tensile and impact testing, the specimens were taken from the pipe of outside diameter 609 mm and wall thickness of 25 mm. Material's mechanical properties for two tested temperatures, i.e., room temperature (RT) and operating temperature (OT) of 540 ˚C, are shown in Tables 2 and 3, respectively.

Table 2. Mechanical properties of material tested at RT

Elasticity modulus E, GPa	Yield stress $R_{p0.2}$, MPa	Tensile strength R_m, MPa	Total elongation A, %	Poisson's ratio v
197	363	458	26.8	0.3

Table 3. Mechanical properties of tested material at OT.

Elasticity modulus E, GPa	Yield stress $R_{p0.2}$, MPa	Tensile strength R_m, MPa	Total elongation A, %	Poisson's coefficient v
138	214	300	29.4	0.3

3. Experiment

The Charpy-V impact tests were performed on the virgin material (VM) 14MoV6-3 steel at RT and at OT, in accordance with standard [7]. Charpy specimens were extracted from two rolling directions, transversal (T) and longitudinal (L), Figure 1 [8].

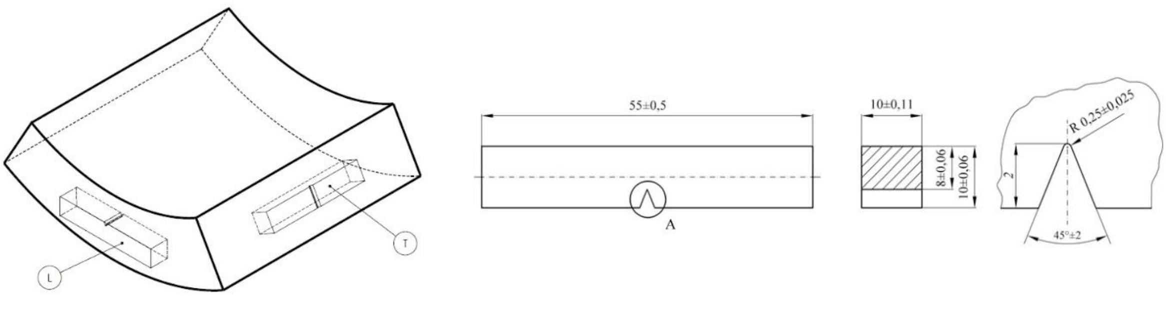


Figure 1. Charpy V specimen and V notch location (L-T orientation of Charpy specimens)

Two typical diagrams, force vs. time, and energy vs. time, obtained by instrumented impact testing are presented in Figs. 2 and 3 for the VM specimens extracted in the direction of pipe rolling (L), and in Figs. 4 and 5 for the VM specimens extracted transversely (T) to the pipe rolling direction, tested at RT, as well as at OT.

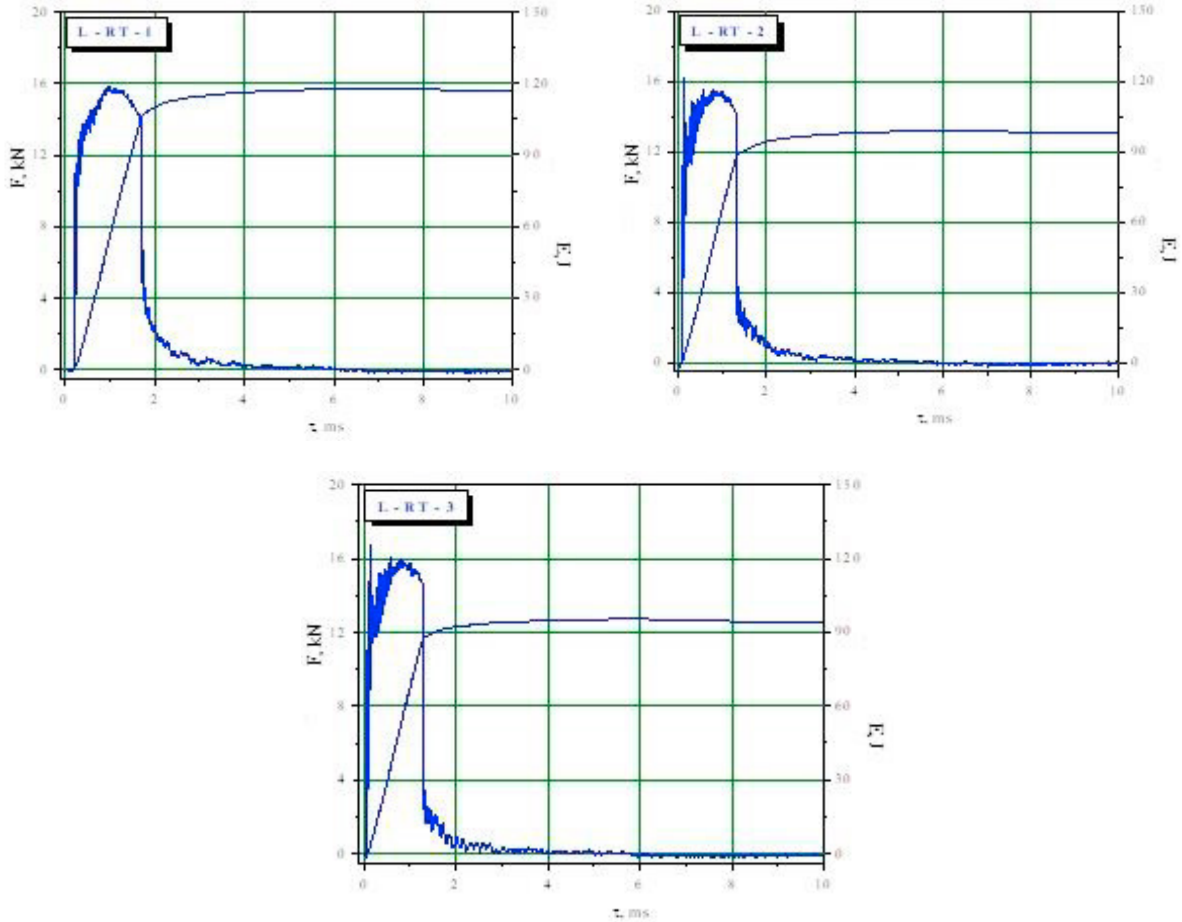
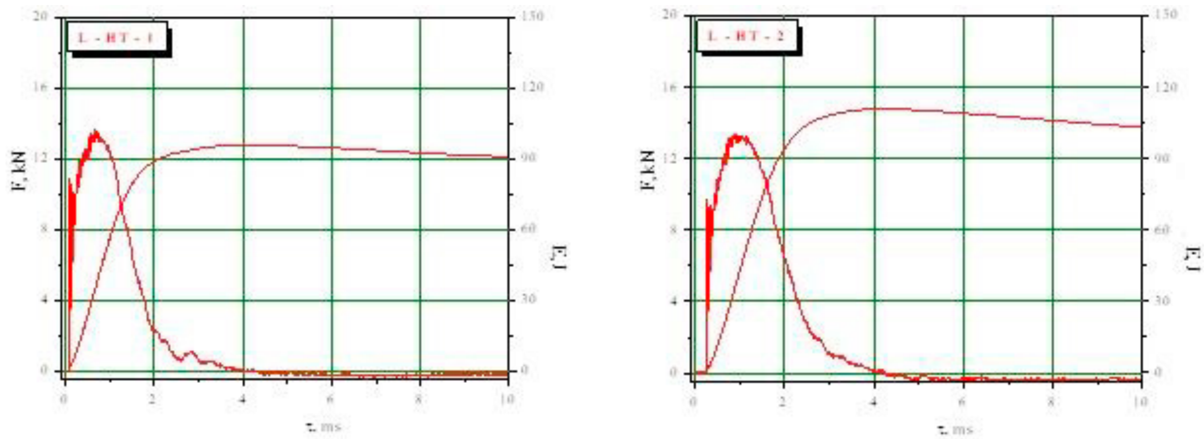


Figure 2. Force vs. time and energy vs. time for VM specimens L1RT, L2RT, L3RT, tested at RT



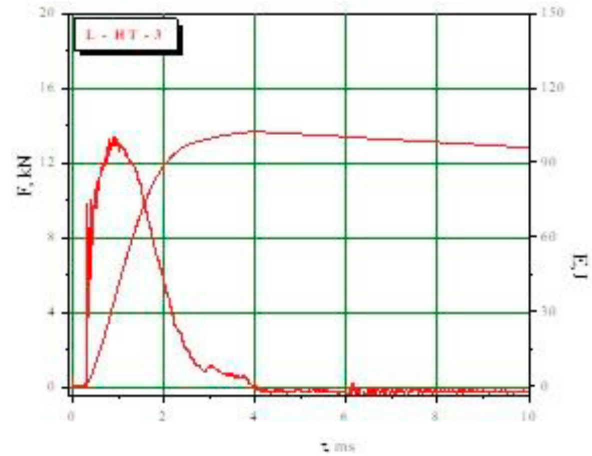


Figure 3. Force vs. time and energy vs. time for VM specimens L1HT, L2HT, L3HT, tested at OT

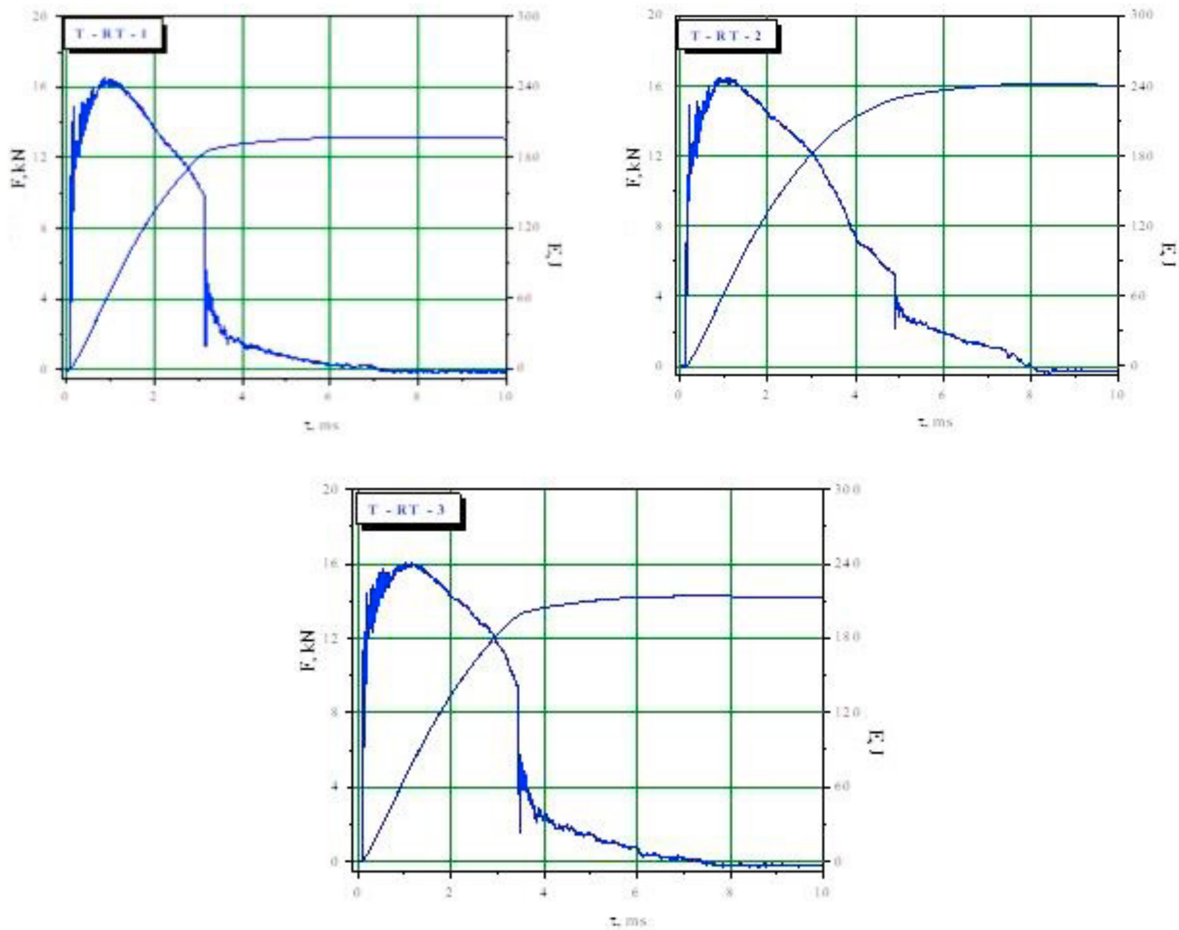


Figure 4. Force vs. time and energy vs. time for specimens T1RT, T2RT, T3RT, tested at RT

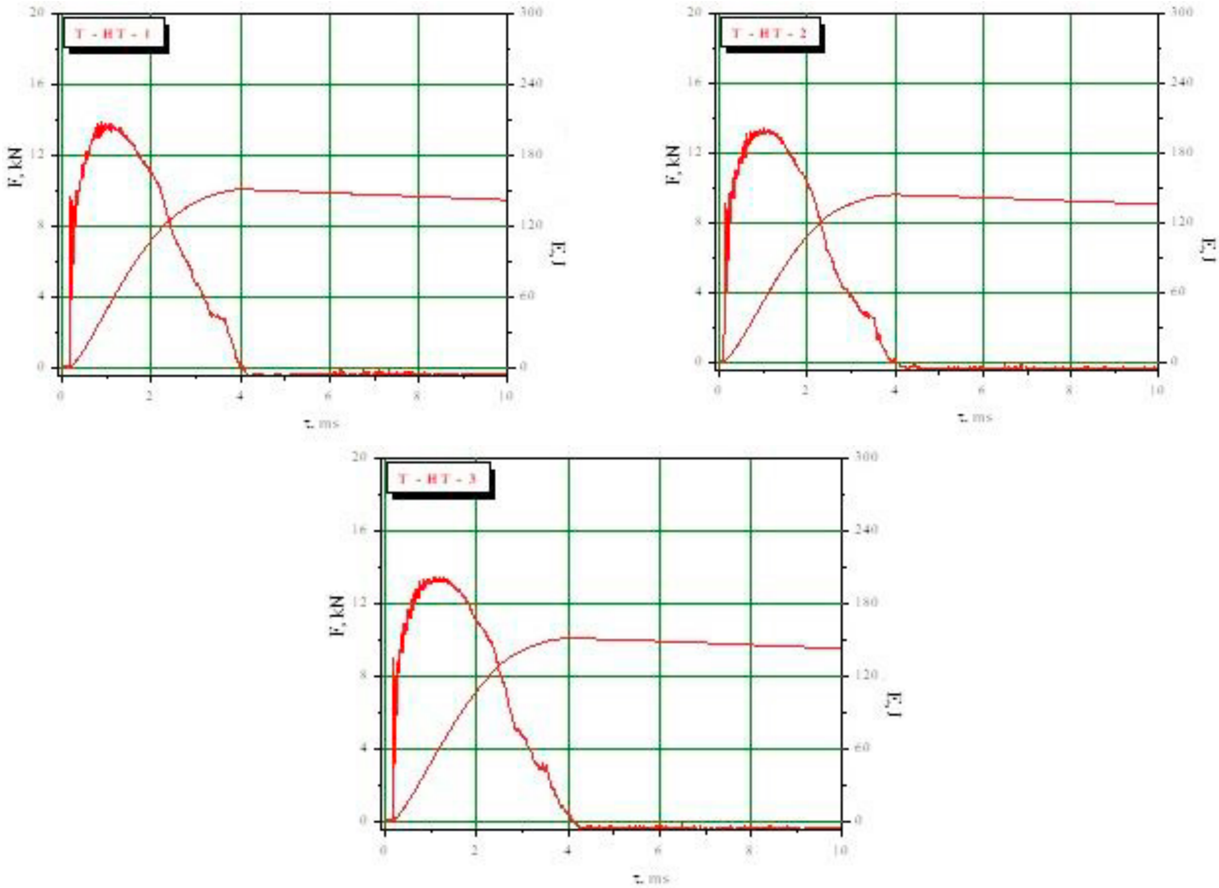


Figure 5. Force vs. time and energy vs. time for specimens T1HT, T2HT, T3HT, tested at OT

4. Results and discussion

Obtained results for total impact energy, and its components, crack initiation and crack propagation energy, are summarized in Table 4 for the specimens extracted in the direction of pipe rolling (L), and in Table 5 for the specimens which were extracted transversely (T) to pipe rolling direction at RT, as well as at OT.

Table 4. Impact energy test results for the specimens extracted in the direction of pipe rolling (L)

Specimen	E_{tot}, J	Mean value, E_{tot}, J	Ei, J	Mean value, Ei, J	E_p, J	Mean value, E_p, J
L - RT - 1	117		61		56	
L - RT - 2	98	103	58	59	40	44
L - RT - 3	94		59		35	
L - HT - 1	91		37		54	
L - HT - 2	103	97	41	38	62	59
L - HT - 3	96		35		61	

Table 5. Impact energy test results for the specimen extracted transversely (T) to pipe rolling direction

Specimen	E_{tot}, J	Mean value, E_{uk}, J	Ei, J	Mean value, Ei, J	E_p, J	Mean value, E_p, J
T - RT - 1	197	217	67	71	130	146
T - RT - 2	241		68		173	
T - RT - 3	213		77		136	
T - HT - 1	142	140	55	59	87	81
T - HT - 2	136		58		78	
T - HT - 3	143		64		79	

The dependence of E_{tot} of tested steel on the test temperature is given in the diagram in Fig. 6 for the specimens sampled in both, L and T-directions.

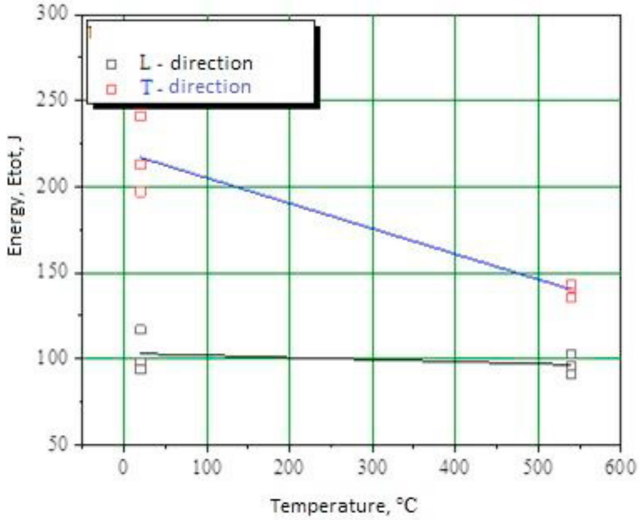


Figure 6. Change in total impact energy with test temperature change

Impact energy results for VM samples taken out in the L- and T-direction and tested at RT and opereted temperature (OT) are presented in the diagrams in Figs. 9.

Based on the obtained results of the impact tests, with the increase in the test temperature, there is a drop in the total impact energy E_{tot}, Fig. 6 and Fig. 9. The obtained values of the total impact energy, for the specimens sampled from the L-direction, range from 103 J obtained at RT to 97 J obtained at OT, and for the specimens sampled in the T-direction range from 217 J obtained at RT to 140 J obtained at OT.

Participation of energy in the initiation of cracks, E_i, for specimens sampled in the L-direction, ranges from 59 J obtained at RT to 38 J obtained at OT. The values of the crack propagation energy, E_p, range from 44 J at RT to 59 J obtained at OT.

Participation of energy in the initiation of cracks, E_i, for specimens sampled in the T-direction, ranges from 71 J obtained at RT to 59 J obtained at OT. The values of the crack propagation energy, E_p range from 146 J obtained at RT to 82 J obtained at OT.

By comparing the results for the specimens taken out from the steel pipe in the longitudinal L-direction at RT and at OT, the values of the total energy and energy of crack initiation are slightly higher at RT than at OT, while the energy required for crack propagation is slightly higher at OT. Also, the maximum force on RT is higher than the force obtained on OT.

By comparing the results for the specimens taken out from the steel pipe in the transverse T-direction, we see that all three energy values, as well as the maximum force, are higher at RT than at OT.

It can be observed that there is no major difference between the values of the maximum force reached in samples taken out from the steel pipe in two different directions at both test temperatures, fig. 2-5. The maximum force achieved on RT is about 13% higher than the force obtained at OT, which is expected because the strength and the hardness are higher on RT.

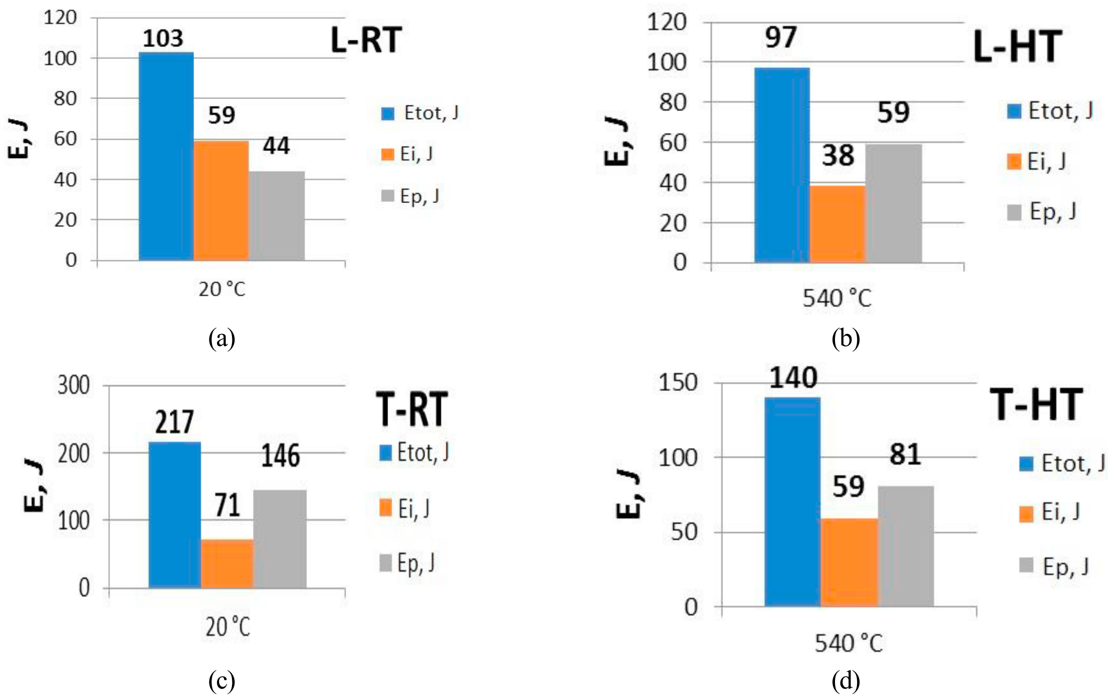


Figure 7. Comparative values of total impact energy, E_{tot}, energy of crack initiation, E_i, and crack propagation E_p for VM samples taken out from the pipe in the L- and T-direction, tested at RT and OT

5. Conclusion

The impact toughness at room temperature and 540°C of specimens made of 14MoV6-3 steel was studied by instrumented Charpy tests. Charpy specimens were extracted from two rolling directions, transversal and longitudinal. Important observations can be summarized from the current study:

- A comparison of the tensile properties of the investigated material tested at room and operating temperature of 540 ˚C, indicates an expected decrease in tensile strength and yield stress at elevated temperatures. The values of the modulus of elasticity also decrease with temperature increasing.
- The results of the impact tests, separated into the energy of initiation and propagation of the crack, indicate a higher participation of the resistance of the material to the propagation of the crack in the case of both, room and operated temperatures, in case when specimens were sampled in the transverse direction.
- In the case of the specimens sampled in the longitudinal direction, there is a slightly higher proportion of the material's resistance to crack initiation at room temperature, while at the operating temperature there is a higher proportion of the material's resistance to crack propagation.

It can be concluded that the relations between total impact energy components were as expected, with crack initiation energy decreasing with temperature, and crack propagation energy increasing at the same time. More important, it was determined that the specimen sampling direction, relative to the rolling direction, had significant influence on the results, indicating far better behavior in specimens taken from the transversal direction.

Further research of this topic will involve calculating of the J-integral, as well as various numerical simulations, based on the experimentally obtained data.

Acknowledgements

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No.451-03-68/2022-14/200135).

References

[1] Server WL. Instrumented Charpy test review and application to tructural integrity. In: Francois D, Pineau A, editors. From Charpy to Present Impact Testing. Elsevier Science Ltd. and ESIS; 2002, 205-212.
[2] Radakovic Z, Sedmak A, Lenkey GyB, Grabulov V. Determination of ductile crack initiation by magnetic emission and potential drop echniques using pre-cracked Charpy specimens. In: Francois D, Pineau A, editors. From Charpy to present impact testing. Elsevier Science Ltd. and ESIS; 2002. p. 71–78.
[3] Hubner P, Pusch G, Correlation between Charpy energy and crack initiation parameters of the J integral concept. In: Francois D, Pineau A, editors, Charpy centenary conference, vol. 1, 2001. p. 209–215.
[4] I. Camagic, S.A. Sedmak, A. Sedmak, Z. Burzic: Influence of temperature on fracture toughness values in different regions of A-387 Gr. B welded joint, Procedia Structural Integrity, Vol. 18, 2019, p. 205-213.
[5] I. Camagic, S. Kirin, A. Sedmak, Z. Burzic: Risk based analysis of temperature and time effects on brittle fracture of A-387 Gr. B welded joint, Procedia Structural Integrity, Vol. 18, 2019, p. 379-384.
[6] I. Camagic, Z. Burzic, S.A. Sedmak, A. Sedmak, D. Lazarevic: Integrity and Life Assessment Procedure for a Reactor, Procedia Structural Integrity, Vol. 18, 2019, p. 385-390.
[7] EN ISO 9016, Destructive tests on welds in metallic materials - Impact tests - Test specimen location, notch orientation and examination, 2013.
[8] Bojana V. Zečević, Effect of operating temperature on the resistance of low carbon microalloyed steel for thermal power plants to crack initiation and growth, Doctoral dissertation (IN Serbian), University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, 2022.