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Determination of ductile-to-brittle transition temperature of NIOMOL 490K steel welded joints

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Abstract

This paper is devoted to the ductile–brittle transition behavior of high strength low alloyed structural steel NIOMOL 490K. This steel grade is designed for welded pressure vessels exposed to dynamic loads, operating at temperatures below zero, and that is why it must have acceptable toughness. Due to its importance for the safety assessment of pressure vessels, a characterization of this steel with Charpy V-notch test in range of temperature between-60 ºC and +60 ºC was undertaken. Ductile-to-brittle transition temperature curves were generated in the present study by using instrumented Charpy pendulum impact test on V-notch specimens. Notches were located in the parent material, heat-affected zone and weld metal. The nil-ductility temperature and tensile properties in temperature range from -60 ºC to +60 ºC are presented in this paper. We used different test temperatures to better understand ductile-to brittle transition response than just use either Charpy energy or other related ductility criteria.

Keywords: Transition temperature, Mechanical properties, Niomol 490K

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1. Introduction

Depending on the material ability, two types of fracture can be distinguished, i.e. brittle and ductile fracture. Ductile materials have a certain degree of plastic deformation before fracture, which is followed by significant amount of absorbed energy, while brittle one is vice versa. It is also known that during brittle fracture low energy is absorbed before fracture, which represents low toughness. But even the ductile materials can break in a brittle manner. Factors that can affect ductile-to-brittle transition (DBT) are temperature decreasing, deformation (or displacement) rate and the presence of a stress concentrator on the part surface, Djordjevic at all (2020). Special attention was paid to temperature influence on the fracture (absorbed) energy, whereby the DBT takes place in the temperature interval (Fig. 1).

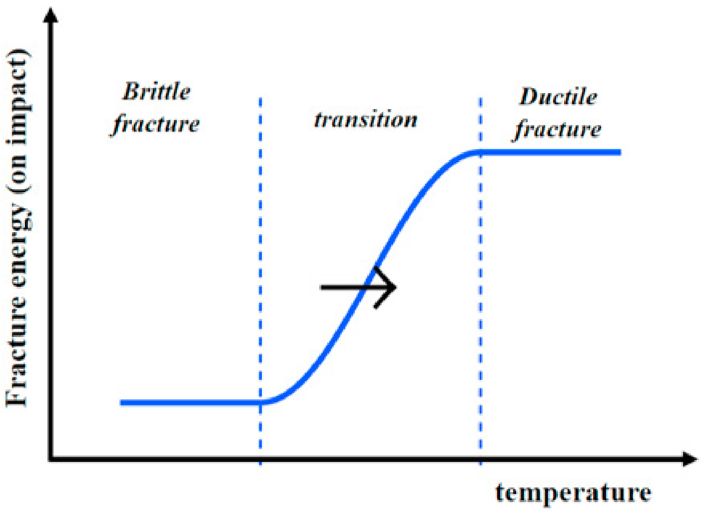


Fig. 1 Dependance of fracture energy on temperature, Djordjevic at all (2020)

As a defining parameter for transition temperature is the temperature at which the total impact energy (impact toughness) drops to 50% of values of total impact energy at room temperature. There is another criterion, criterion 27 J. That's the temperature at which the total impact energy is 27 J. Manjgo (2008) Criterion 27 J is the most widely applied and that is what we use to define transition temperature values.

Brittle fracture was caused by unstable crack growth that may occur in this area. Therefore, it is necessary from the aspect of structural integrity to determine the material fracture toughness in this sensitive area. The focus of studies with multidisciplinary approaches concerning ductile-to-problem was investigation and examination of their characteristics, thus lead to obtaining predictive behavior that depends on temperature. The final aim was structural integrity assessment of constructions made of HSLA steels, as well as defining the possibilities and limitations at low temperatures (more precisely in transition temperature region), Heerens and Read (1988), Berejnoi at all (2016).

2. Material

The investigated material is micro-alloyed high strength steel, commercial mark NIOMOL 490K steel, of yield strength min. 490 MPa and specified nil-ductility transition (NDT) temperature of –60 ºC, produced by Slovenian Steel work company ACRONI Jesenice. It is primarily applied for dynamic loading conditions and at low temperatures. Chemical composition of the investigated steel is given in Table 1 and its mechanical properties are shown in Table 2.

Table 1. Chemical composition of NIOMOL 490K, wt. %

C	Si	Mn	P	S	Cr	Cu	Al	Sn	Ni	Mo	As	Nb	N	O
0.09	0.34	1.06	0.009	0.002	0.12	0.17	0.41	0.005	0.9	0.26	0.008	0.06	0.0082	0.0075

Table 2. Mechanical properties of the investigated steel.

Direction	Yield strength	Ultimate strength	Elongation	Impact energy
	$Rp_{0,2}$ (MPa)	R_m (MPa)	A (%)	ISO-V (J)
L-T	560	615	20.8	237, 262, 260
T-L	555	619	16.8	241, 262, 252

2.1. Welding technology

The welding regime of NIOMOL 490K steel requires a selection of proper parameters to avoid deterioration of mechanical properties. The welding thermal cycle depends on heat input, material thickness, operating temperature of parent material (PM) and preheating temperature as well as the welded joint shape and size, Coseru et all. (2014).

NIOMOL 490K steel grade belongs to a group of micro-alloyed steels with molybdenum and with the minimum yield strength of 490 MPa, and it is used for manufacturing of pressure vessels. Successful application of this steel grade depends on the degree of deterioration of the PM during welding. A detailed study of mechanical properties can ensure a certain level of safety and reliability for practical application of welded structures made of NIOMOL 490K.

Heat affected zone (HAZ) and weld metal (WM) are crucial regions for low toughness and higher transition temperature values. These regions usually are the place where cracks might occur especially in welded joints of high strength steels.

Arc welding is mostly used method for welding micro-alloyed steels. With this process, high quality welded joints can be achieved, and is also suitable for high automation and robotization. As filler material for welding the tested steel we used Ø 3.25 mm powder-filled wire Fluxofil 41, submerged arc welding wire $NiMO_2$, Ø 4 mm coated electrodes SH-2V. The specified chemical composition of consumables is given in Table 3.

Table 3. Chemical composition of the filler metals produced in ACRONI Jesenice

Filler Metals	Elements %									
	C	Si	Mn	Cr	Mo	Ni	S	P	Cu	Ti
Fluxofil 41 (in pure CO_2)	0.05	0.28	1.09	0.04	-	1.3	0.007	0.009	-	0.007
SAW 2 $NiMO_2$ (Ø 4 mm) + OP 40 TT	0.08	0.28	1.05	0.05	0.36	1.6	0.008	0.022	0.19	-
SH-2V, Ø 4 mm	0.08	0.27	1.58	0.05	-	0.88	0.004	0.19	-	-

Heat inputs shown in Table 4. were calculate using Eq. 1, Toth (1978).

$$Q = \mu VI/v \tag{1}$$

Here, V is arc voltage in volts (V), I is welding current in amperes (A) and v is welding speed in cm/s.

Table 4: Welding parameters and heat input values

Specimens		Heat input per unit length (KJ/cm)	Current (A)	Voltage (V)	Welding speed (cm/s)
Wire for submerged arc welding (SAW) $2NiMO_2$ + powder OP4TT		22.5	600	30	0.8
Flux cored wire for metal active gas (MAG) welding, FLUXOFIL 41 Ø 3.25 mm in pure CO_2 protective layer		8.5	190	21	0.47
Plated electrodes SH-2V, Ø 4mm, EVB NiMo, Ø 3.25 mm	for electrode with Ø 3.25 mm	7	130	23	0.4
	for electrode with Ø 4,0 mm	8.8	160	25	0.45

3. The use of instrumented Charpy impact test to determined transition temperature

A pendulum impact test, known as Charpy test, was performed in order to determine the amount of energy dissipated during fracture, which is a measure for the fracture toughness of the material, as function of the temperature. The tests were performed according to ASTM E23 standard on standard (10x10x55) mm V-notched specimens (Fig 2). Test was performed on the instrumented Charpy machine AMSLER 150/300 J.

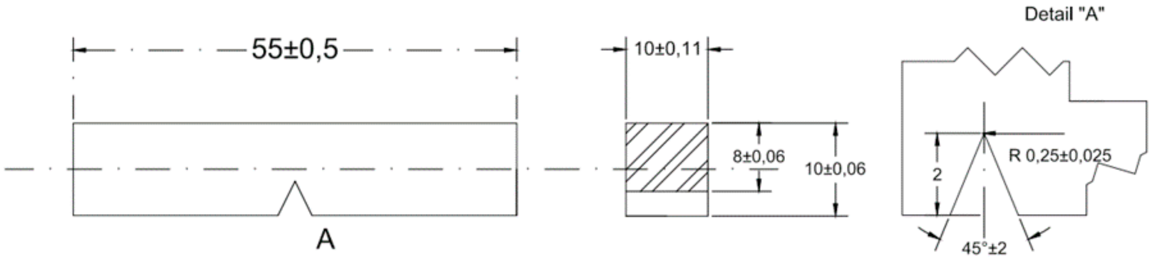
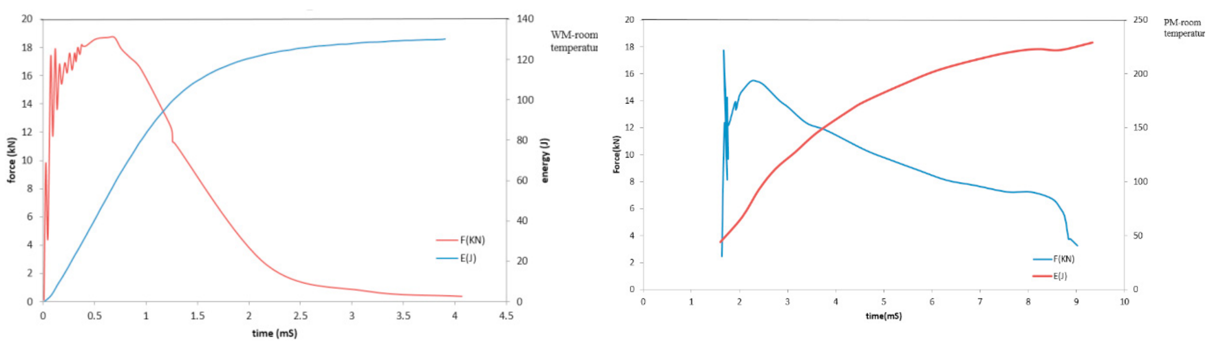


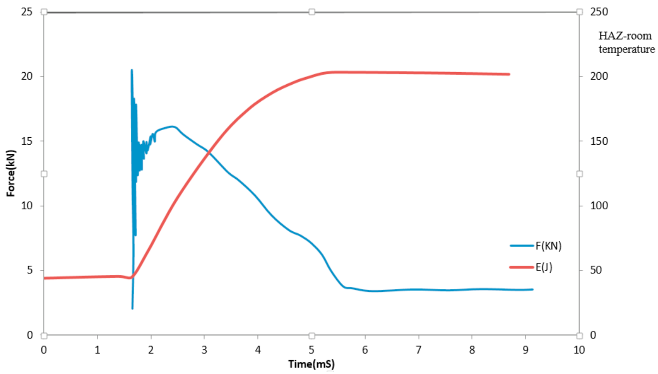
Fig.2. Impact energy test specimen

Three types of specimens with the notch in PM, WM and HAZ were tested at temperature range from -60 ºC to +60 ºC. Following the ASTM E23 standard, the sample was tempered 10 minutes at the required temperature and then transferred to the machine and tested in less than 10 seconds.

Diagrams load – time and force – time, for all three PM, WM and HAZ specimen types tested at room temperature (RT), are shown in (Fig. 3).



(a) (b)



(c)

Fig.3. (a) Diagram Force – Time, Energy – Time for WM (b) Diagram Force – Time, Energy – Time for PM (c) Diagram Force – Time, Energy – Time for HAZ

4. Discussion

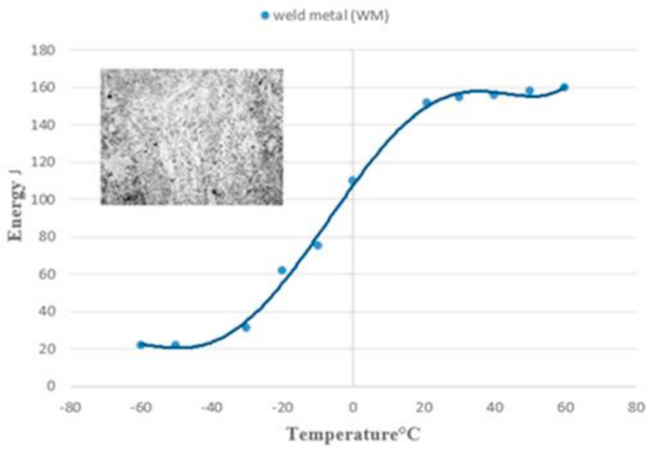
Transition from ductile to quasi brittle failure is defined as first critical temperature, and the transition from quasi-brittle to brittle failure is second critical temperature. Second critical temperature that defines the transition to brittle failure is called transition temperature or nil-ductility temperature (NDT), Lenkey (2000).

Ductile brittle transition temperature (DBTT) is used to measure the low temperature toughness of the material. Transition temperature has been determined at conventional level of 27 J and called TK27. Values for transition temperature for WM, PM and HAZ are shown in Tab. 5.

Different curve trends are notice for the different regions of the welded joint. PM has DBTT at -138 ^{0}C which is lower than the required minimum. HAZ show a very low DBTT of -88 ^{0}C but much lower toughness and higher transition temperature of -50 ^{0}C is notice in the case of WM specimens.

Individual diagrams of temperature and energy dependence of PM, WM and HAZ notched specimens are shown in Fig. 4.

(a)



(b)

(c)

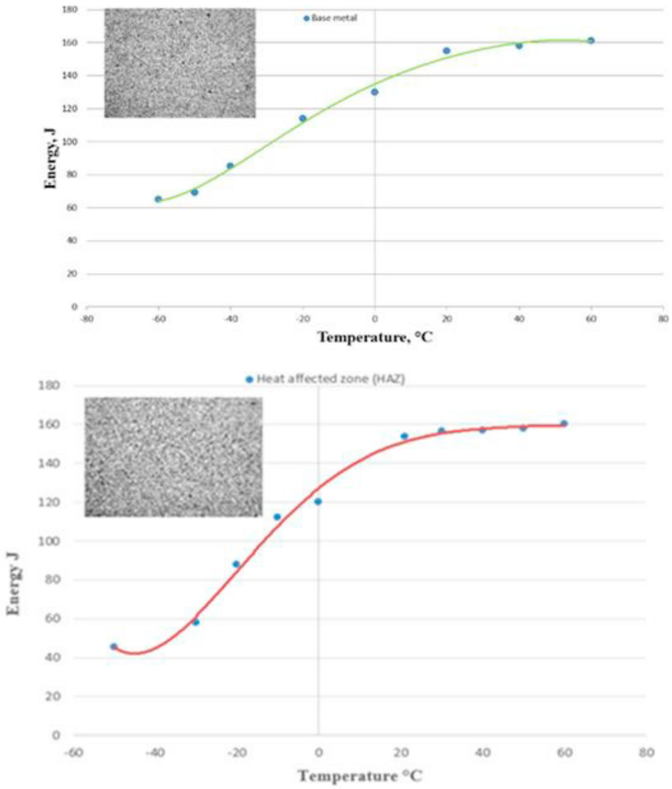


Fig 4. DBTT curves for specimens made of NIOML 490 K steel with the notch positioned in: (a) WM (b) PM (c) HAZ

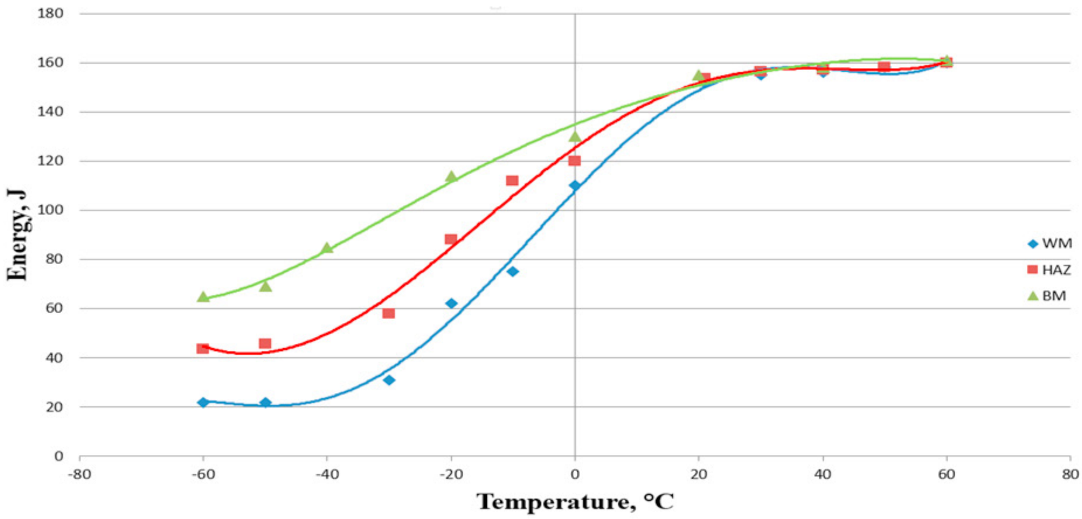


Fig.5. Temperature curve of ductile brittle transition of NIOML 490 K steel

Table 5. Transition temperature for NIOMOL 490 K

NIOMOL 490 K	Nil-ductility-transition temperature, (°C)
Parent metal	-138
Weld metal	-50
Heat affected zone	-88

5. Conclusion

As can be seen in Fig 5, three zones can be noticed:

1. upper threshold zone with maximal impact energy values,
2. lower threshold zones where the values of impact energy are minimal and
3. the transition area with a drop in impact energy from the upper to the lower threshold.

Based on the values obtained from the diagram shown in Fig. 5., nil-ductility transition temperature for PM is -138 °C, for WM -50 ° C and for HAZ -88 ° C. If we observe constituents of the welded joint, higher value of transition temperature was obtained in specimen with notch located in HAZ than the specimen with notch located in WM.

Acknowledgements

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