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Experimental Determination of J_{Ic} for a HSLA Steel Welded Joint

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Abstract

Most serious weldment failures have catastrophic consequences in terms of damage to other equipment, loss of production, and risks to worker health and safety. For the above reasons, there is a tendency to find the line between safety and disaster, and this requires a guarantee of the integrity of the welded structure even if a crack is present. The structural and mechanical heterogeneity of a welded joint affects its resistance to cracking in both the elastic and plastic regions. Therefore, it is important to define the test method and the position of the fatigue crack. The behavior of an elasto-plastic material, during stable crack growth can be described by the J-Δa diagram. As the crack propagates, a point on the curve is defined, which represents the critical value of the J-integral. The aim of this experiment is to determine J_{IC} value and the procedure is reflected in the determination of the R-curve, i.e., the J–Δa curve, which consists of the value of the J-integral for uniform crack increments Δa. In this paper, precracked SEN(B) specimens with the fatigue crack positioned in the weld metal (WM) were tested according to standard ASTM E1820 at room temperature (RT), -20 ^{0}C and -30 ^{0}C.

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Keywords: J-integral; J-R curve; HSLA steel; welded joints

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1. Introduction

NIOMOL 490K belongs to the class of molybdenum microalloyed steels, of yield strength min. 490 MPa and specified nil-ductility transition (NDT) temperature of –60ºC, produced by Slovenian Steel work company ACRONI Jesenice. 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. The successful application of this steel depends on the grade deterioration of the properties of the base metal during welding. Maksimovic (2022)

Due to the wide range of applications in many industries, the integrity assessment of welded structures is of great significance. Welded joint is the weakest link of a welded structure. Hemer (2020) In the case of welded structures which are made of microalloyed steel, there is a problem of crack existence, so it is necessary to examine whether the welded joints are prone to crack initiation and growth.

The stress intensity factor K_I, the J-integral, the crack-tip opening displacement (CTOD), are the most important parameters used in fracture mechanics, and are used for assessment material crack resistance. Their critical values K_{Ic}, δ_C and J_{Ic}, can be used as properties of the homogeneous material. Zhu (2012)

The idea of this experiment is to determine the critical value of the J-integral, J_{Ic}, and the test procedure is reflected in obtaining the R-curve, that is, the J-Δa curve, which consists of the value of the J-integral for uniform crack growth Δa. The J-R curve is experimentally determined using the method that follows elastic deformation together with measured crack mouth opening.

2. Material and experimental

The investigated material NIOMOL 490 K is micro-alloyed high strength steel of yield strength min. 490 MPa which has a guaranteed nil-ductility transition temperature of –60 ºC, aimed for dynamic operating conditions at low temperatures.

The results of the chemical composition of the investigated steel used for fabrication of butt-welded plates of 30 mm thickness are given in Table 1. The results of tension tests obtained at RT of the parent material (PM) and the welded joint (WJ) are shown in Figs. 1 and 2 respectively, and their tensile properties (mean values) were determined using 3 PM specimens and 3 WJ specimens, are listed in Table 2.

Table 1. Chemical composition of NIOMOL 490K steel, 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. Mean tensile properties values at RT of the investigated specimens PM and WJ.

Material	Yield strength $R_{p\,0.2}$, MPa	Ultimate strength R_m, MPa	Fracture strain, %
PM	544	610	26.47
WJ	620	650	25.5

The influence of the heterogeneity of the structure and mechanical properties of the welded joint is primarily reflected in the position of the fatigue cracks tip as well as the properties of the area through which the fracture propagates. The experiments were conducted on fatigue precracked single edge notched bend SEN(B) specimens extracted along the length of the welded seam, using single specimen elastic compliance method according to ASTM E1820 standard. Plane-strain fracture toughness K_I were determined in order to evaluate the behavior of the welded joint in the presence of a crack-type fault, as the most dangerous of all structural faults, Manjgo (2008), Mijatovic et al (2019), Jovanpvoc et al (2020).

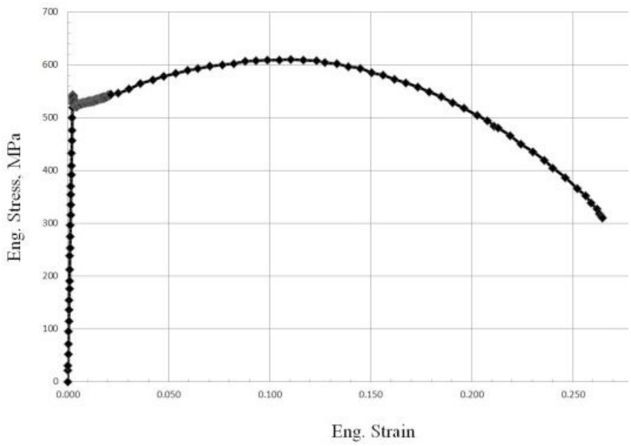

Fig1. Engineering stress-engineering strain diagram for PM tested at room temperature

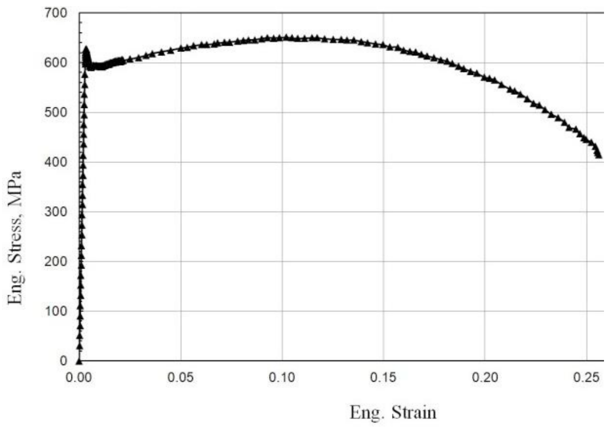

Fig 2. Engineering stress-engineering strain diagram for WM tested at room temperature

Test was performed at three different temperatures (RT, -20 °C and -30°C) on the electromechanical testing machine, Fig. 3. Crack tip opening is obtained by special extensometer, with a measuring accuracy of ±0,001 mm.

Fig.3 SCHENCK TREBEL RM400 testing machine

Based on the data collected from the testing machine, diagrams load (*F)* – crack tip opening (*CTOD)* were drawn and then the *J–Δa* dependance is constructed, Fig 4. The critical *J*- integral value, J_{Ic}, is obtained from the regression line. After obtaining J_{IC} values, values of the critical stress intensity factor (SIF) K_{Ic} were determined using Eq. (1). Anderson (1990):

$$K_{IC} = \sqrt{\frac{J_{IC} \cdot E}{1-\nu^2}} \tag{1}$$

where *E* denotes elasticity modulus of the investigated steel and *v* its Poisson's ratio. Results of critical *J*-integral and SIF values, J_{Ic} and K_{Ic}, are presented in Tab. 3.

Table 3: Values of J_{IC} and K_{IC}

Temperature, °C	*a*, mm	*Δa*, mm	J_{Ic}, kJ/m^2	K_{IC}, MPa m$^{1/2}$
RT	11.617	0.414	222	226
-20	10.519	0.391	147	184
-30	10.982	0.312	118	165

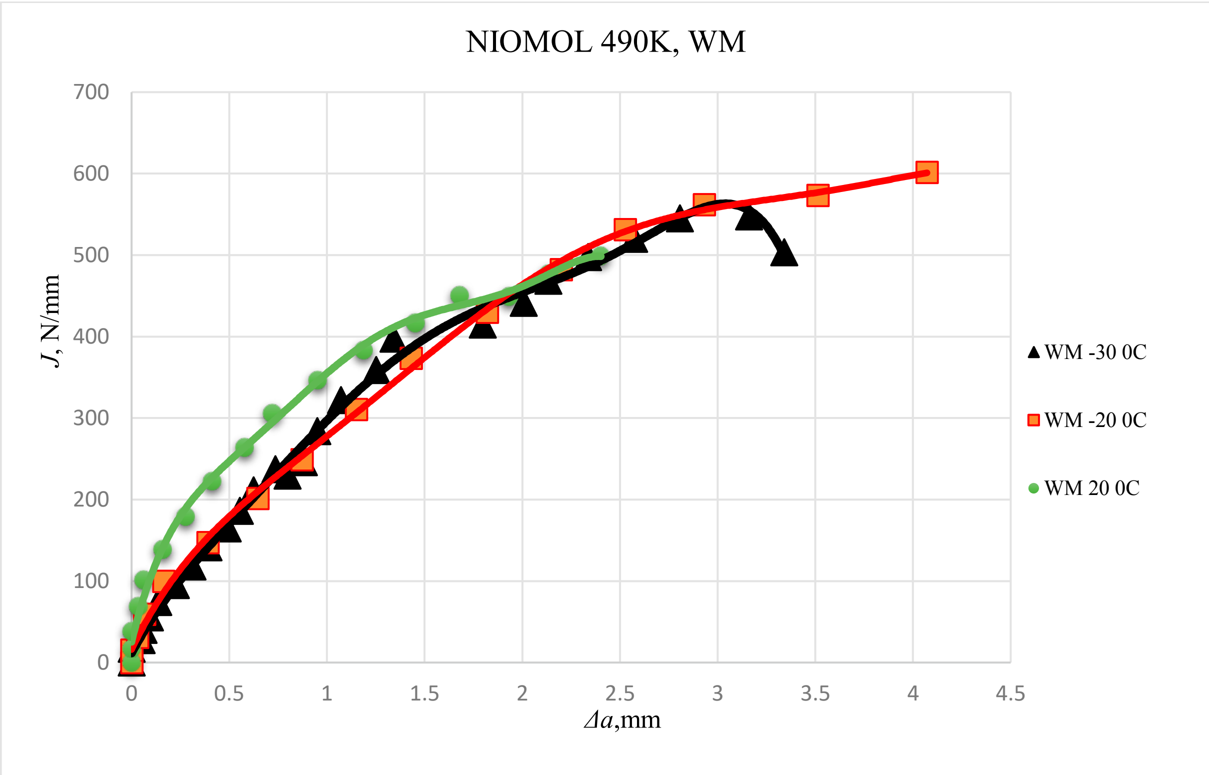

Fig. 4 J – R curves of NIOMOL 490K welded joints tested at different temperatures

3. Results and Discussion

The structure and mechanical heterogeneity of the welded joint influence the crack development in the elastic and plastic regions. Therefore, it is necessary to define the position of the fatigue crack when examining fracture mechanics, Bulatovic (2023).

The obtained values for WM are within the limits of the linear values for this type of steel and are reported in Tab. 3. We can see that values for WM obtained by testing specimens at the RT are $J_{Ic} = 222$ kJ/m^2, $K_{Ic} = 226$ MPa m$^{1/2}$, at the temperature -20 ^{0}C, obtained values are $J_{IC} = 147$ kJ/m^2, $K_{IC} = 184$ MPa m$^{1/2}$ and at the temperature -30 ^{0}C, values are $J_{IC} = 118$ kJ/m^2, $K_{IC} = 165$ MPa m$^{1/2}$.

4. Conclusion

Great interest in the application of fracture mechanics testing of welded joints encountered limitations already at the beginning, because at least 10 specimens should be examined to determine some of the fracture mechanics parameters of the welded joint. The application of fracture mechanics to the examination of welded joints is large, and the reason is, first of all, a better and more complete understanding of the behavior of a welded joint with a crack based on data analysis is obtained in those tests, Burzic (2001).

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