INTERNATIONAL SCIENTIFIC CONFERENCE ON
ADVANCES IN MECHANICAL ENGINEERING
PROCEEDINGS

EXPERIMENTAL *J*-INTEGRAL DETERMINATION OF DIFFERENT WELDMENTS REGION AT LOW TEMPERATURE

**[1]*MILOVIĆ Ljubica*, [2]*ALEKSIĆ Vujadin*, [3]*MARINKOVIĆ Aleksandar*,
[4]*LAZOVIĆ Tatjana*, [5]*STANKOVIĆ Miloš***

[1]*Associate professor*
[1]*University of Belgrade, Faculty of Technology and Metallurgy*
acibulj@tmf.bg.ac.rs

[2]*Researcher*
[2]*Institute for testing of materials-IMS Institute*
vujadin.aleksic@institutims.rs

[3,4]*Associate professor*
[3,4]*University of Belgrade, Faculty of Mechanical Engineering*
[3]*amarinkovic@mas.bg.ac.rs*, [4]*tlazovic@mas.bg.ac.rs*

[5]*Researcher*
[5]*University of Belgrade, Faculty of Mechanical Engineering, Innovation Center*
shomyguca@yahoo.com

Abstract
Behavior of welded joint regions (parent material, weld metal and heat-affected zone) in the presence of crack is presented. Specimens were made of high-strength low-alloy steel and were tested at -40°C. Diagrams load versus crack opening displacement, resistance curves and J versus crack extension are analyzed.

Keywords: *fracture mechanics, crack, high-strength low-alloy steel, J integral.*

1. INTRODUCTION

Classical approach to metallic welded structures calculation based on the assumption that the material is homogeneous and isotropic is represented by allowable stress design and safety factor. Such design approach turned out to be not sufficiently reliable because structure failures during their exploitations may occur under stresses that are less than allowable ones. Main reason for that are material defects existing in real structures. Cracks are the most dangerous among those defects.

The majority of metallic structures are manufactured by welding. No matter how good a welded joint is carried out, it represents a defect of material because it disrupts its homogeneity. That is why a welded joint is potential location where cracks can initiate and represents stress concentrators.

In order to have a complete metallic structure characterization, it is necessary to understand material behaviour in the presence of cracks, i.e. the estimation of material resistance to crack initiation and propagation. As the result of such approach we get structures of lower mass with significantly reduced fracture risk.

Elastic-plastic fracture mechanics study crack growth after material yield stress is exceeded and is applied to materials that exhibit time-independent, nonlinear behaviour (i.e., plastic deformation) [1]. Energy parameter assessing material resistance to crack propagation in elastic-plastic region is defined by J contour integral which describes crack-tip singularity. A critical value of J is a size-independent measure of fracture toughness. Its critical value for Mode I fracture, J_{IC}, represents elastic-plastic fracture mechanics parameter [2].

Dependence of J integral versus crack extension is called J-R or R resistance curve and it represents fracture mechanics parameter which defines material resistance to crack development [3].

In this paper J integral is experimentally determined on specimens taken from butt welded plates made of high strength low alloyed steel (HSLA) for shipbuilding and pressure vessels manufacturing.

2. MATERIAL AND METHODS

The manufacturing of welded structures using HSLA steels is recommended because structural mass is reduced due to high strength, saving the material and energy.
HSLA steel NIONIKRAL 70 (NN70) used in this experimental investigation was produced in electro furnace, casted in ingots and rolled into slabs and finally rolled in plates 16 mm thick [4]. Its chemical composition is given in Table 1, while its mechanical properties are given in Table 2.

Table 1 Chemical composition of NN70 (weight %)

C	Si	Mn	P	S	Cr	Ni	Mo	V	Al
0.106	0.209	0.220	0.005	0.0172	1.2575	2.361	0.305	0.052	0.007

Table 2 Mechanical properties of NN70

Specimen orientation	Yield stress $R_{p0,2}$, [MPa]	Tensile strength R_m, [MPa]	Total impact energy tested at -40°C E_{tot}, [J]
PM, parallel to rolling direction	780	820	107
WM	718	791	28
HAZ	750	800	57

For fracture mechanics testing, standard SE(N)B specimen was used, Figure 1. Specimen dimensions were B=12 mm, W=16 mm, $2s$= 64 mm, a_0/W=0.5, where s is half distance between support rollers.

Specimens were tested using partial unloading testing technique on universal testing machine INSTRON 8803 of 500 kN capacity at temperature of -40°C.

Fatigue cracks were positioned in parent material (PM), weld metal (WM) and heat-affected zone (HAZ). Current crack length and J-integral values were calculated using standard testing procedure according to ASTM E 1820-08 [5]. During testing, the temperature was kept at -40°C ±1°C using liquid nitrogen. *CMOD* values were measured using standard INSTRON clip gage. Load was recorded graphically and digitally. Commercial software was used for data acquisitioning.

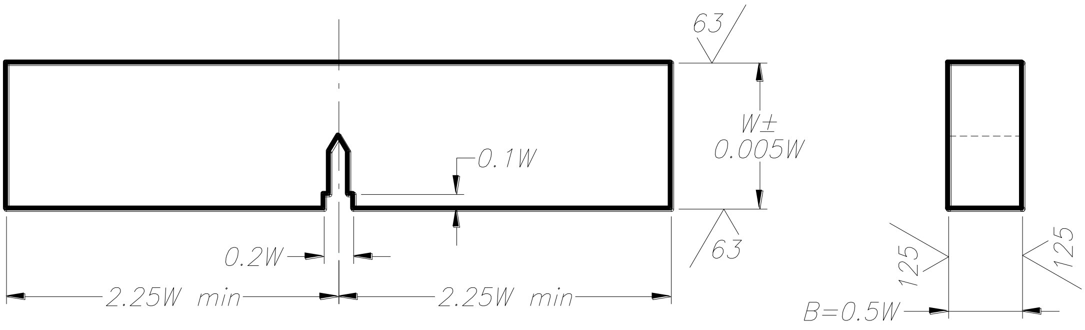

Figure 1. SE(N)B specimen made of NN 70

3. RESULTS AND DISCUSSION

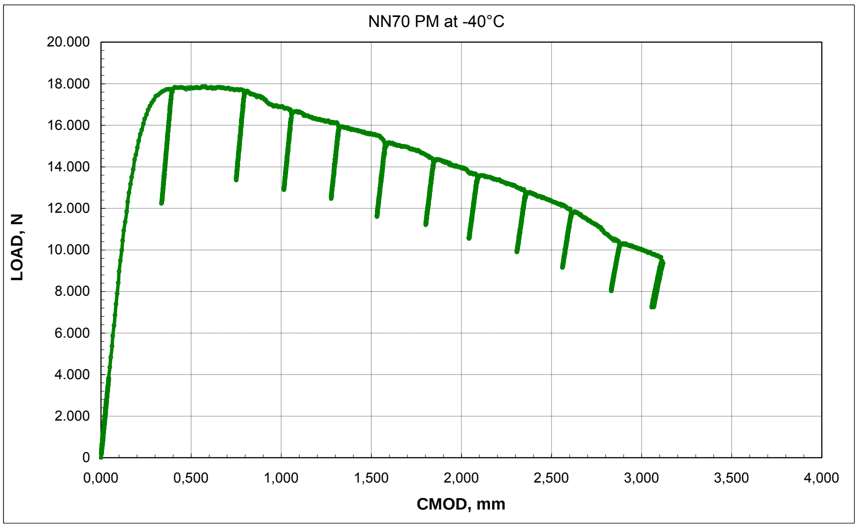

Figure 2. Load-CMOD curves for PM obtained at test temperature of -40°C

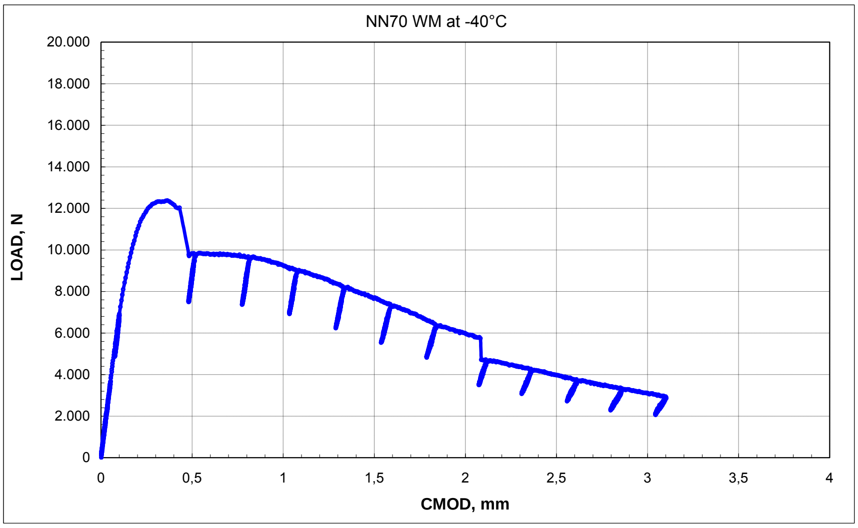

Figure 3 Load-CMOD curves for WM obtained at test temperature of -40°C

Obtained curves load versus *CMOD*, for different welded joint constituents are shown in Figures 2, 3 and 4.

Characteristic resistance curves for different welded joint constituents are shown in Figure 5.

J_{IC} was calculated according to standard ASTM E 1820-08 and obtained curves are presented in Figures 6, 7 and 8.

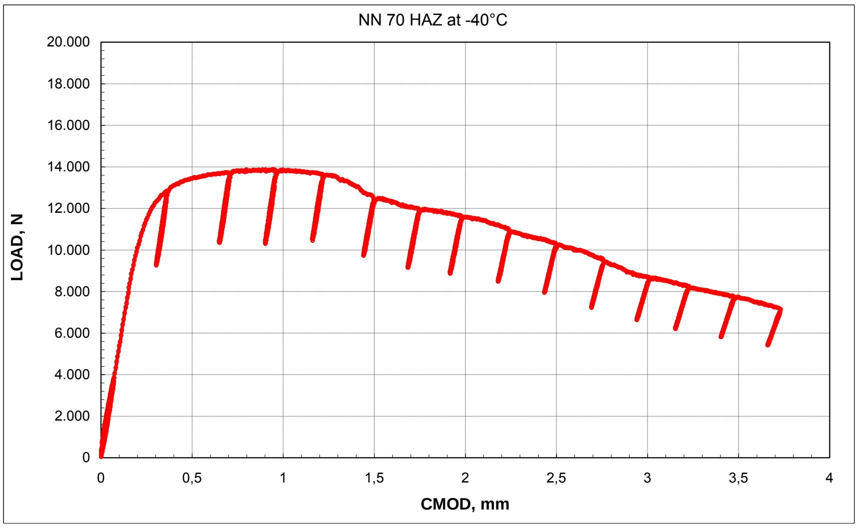

Figure 4. Load-CMOD curves for HAZ obtained at test temperature of -40°C

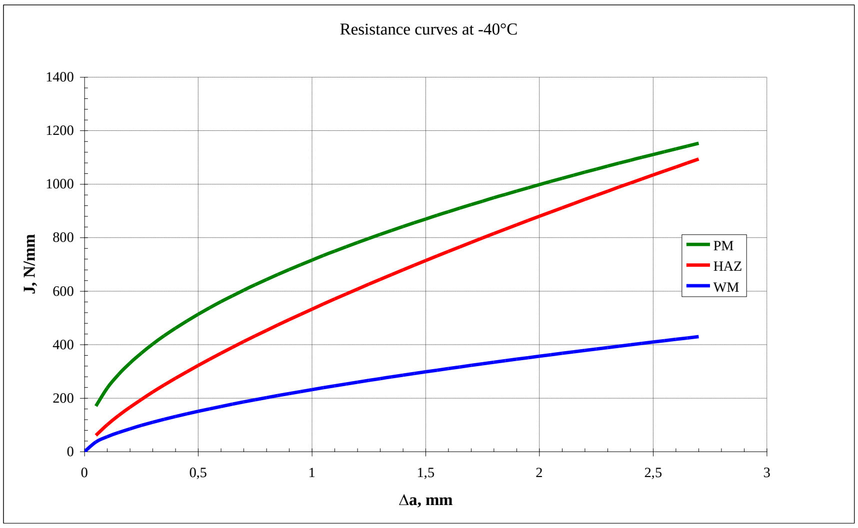

Figure 5. J-R curves for PM, WM and HAZ obtained at test temperature of -40°C

It can be seen from given mechanical properties in Table 2, that PM has a satisfactory toughness whereas WM is boundary acceptable according to code of practice for pressure vessels design. HAZ toughness is greater than those of WM which may be explained by notch position; the notch was most probably positioned in local softened HAZ with higher impact toughness than in WM but lower comparing to PM.

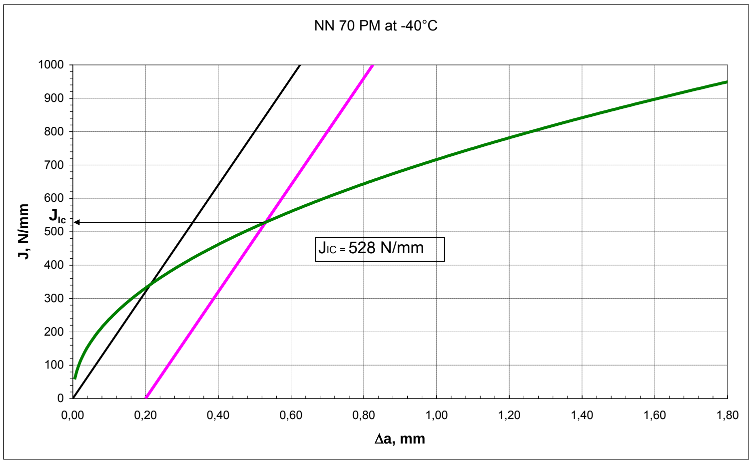

Figure 6. Plot J versus Δa for PM obtained at test temperature of -40°C

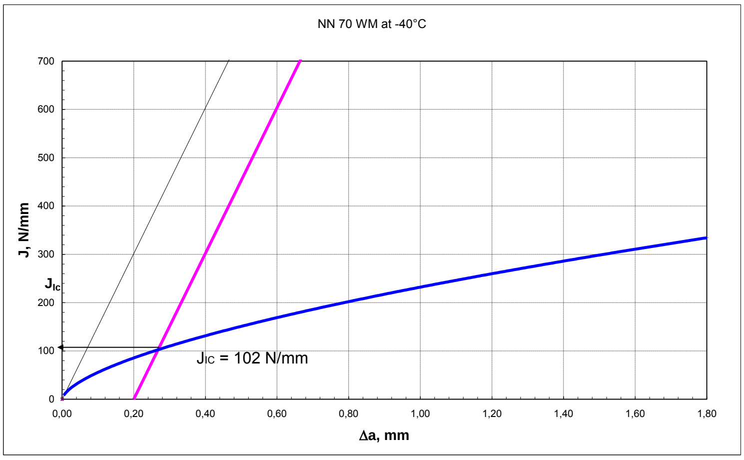

Figure 7. Plot J versus Δa for WM obtained at test temperature of -40°C

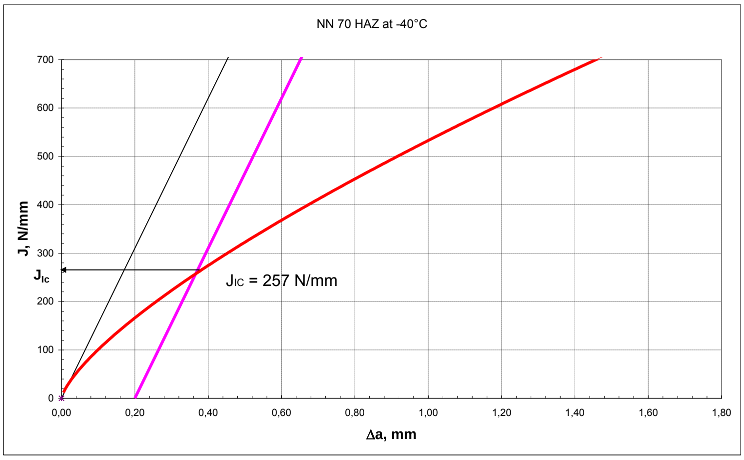

Figure 8. Plot J versus Δa for HAZ obtained at test temperature of -40°C

Load versus *CMOD* curves shown in Figures 2, 3 and 4 describes the behaviour of notched specimen exposed to load. PM curve, Figure 2, shows stable crack growth during complete experiment. Maximal load of 17.867 N was reached at *CMOD* = 0.579 mm. PM exhibits good behaviour under load at temperature of -40°C, curve is continual, no pop-in, which may indicate that NN 70 is suitable for producing of pressure vessels for low temperature operating conditions. In WM, Figure 3, pop-in can be seen meaning that, when crack entered in local brittle zone, it propagated fast, after that crack entered in zone of higher toughness where had continued to grow stably. Crack propagated until the end of experiment when clip-gage linear capacity was exhausted, at *CMOD* value of 3.103 mm. In Figure 4 it can be observed that fatigue crack was positioned in locally softened zone of HAZ with higher toughness, so the growth of crack was stable. HAZ behaviour is similar to PM only that maximal load in HAZ (13.872 kN) was reached at lower load values than in PM but also at higher *CMOD* values (0.944 mm) than in PM, indicating good toughness in HAZ.

Resistance curves given in Figure 5 show the energy amount needed for crack propagation. Relatively high values are needed for crack propagation in PM, for 1 mm of propagation J was approximately 720 N/mm. J value in WM were drastically lower comparing to PM (for crack propagation of 1 mm J was approximately 235 N/mm). J value in HAZ are lower than for appropriate ones for PM but much higher than for WM (for crack propagation of 1 mm J was almost 520 N/mm) which can be explained by the fact that crack was positioned in local softened zone with surprisingly high toughness. After stable crack growth through HAZ, crack reached PM where continued to grow stably.

Values of J_{IC} parameter are used for characterization of material resistance to crack growth. Experimentally obtained values for J_{IC} at -40°C of PM show relatively high value of 528 N/mm, Figure 6, and J_{IC} value for WM was 102 N/mm showing that, in pressure vessels, the weakest part will be WM, Figure 7. High J_{IC} value in HAZ of 257 N/mm, Figure 8, confirms the suitability of investigated welded material for pressure vessel fabrication.

4. CONCLUSION

Impact testing ant fracture mechanics testing show that NIONIKRAL 70 steel is suitable for manufacturing of pressure vessels for applications up to -40°C.

5. ACKNOWLEDGEMENTS

Authors acknowledge the financial support of the Serbian Ministry of Science, project TR 35011. The authors are thankful to Peter Rozsahegyi, Bay-Logi Institute for Logistics and Production Systems, Miskolc, Hungary, for valuable help in experiments. The authors also express their appreciation to Professor Blagoj Petrovski from the University of Belgrade, for invaluable help and suggestions in writing this paper.

6. REFERENCES

[1] **ANDERSON, T. L.:** *Fracture mechanics*, Taylor &Francis, USA, 2005, 636 p.
[2] **RICE, J. R.:** *A Path Independent Integral And Approximate Analysis Of Strain Concentration By Notches And Cracks*, Journal of Applied Mechanics, 1968, 35: pp. 379-386.
[3] **SEDMAK, S., PETROVSKI, B., SEDMAK, A.:** *The Resistance to Crack Growth of Different Regions of Weldments in a Real Structure*. International Journal of Pressure Vessels & Piping, 1992, 52: pp. 313-335.
[4] **MILOVIĆ, LJ., VUHERER, T., ZRILIĆ, M., MOMČILOVIĆ, D., JAKOVIĆ, D.:** *Structural Integrity Assessment Of Welded Pressure Vessel Produced Of HSLA Steel*, Journal of Iron and Steel Research International, 2011, 18(1-2): pp. 888-892.
[5] *ASTM International E 1820* (2008) *Standard test method for measurement of fracture toughness*, 48 p.