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NT2F18

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# 18th International Conference on New Trends in Fatigue and Fracture

## Fatigue and Fracture at all Scales


**Editors:**

**Luis Reis, Manuel Freitas, and Vitor Anes**



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| Day 1 - Wednesday - 18th July | | |
|---|---|---|
| **Time** | **Room Açores** | **Room Navegadores** |
| 8.00h | Reception/Registration | |
| 8.45h | **Opening conference** (Chairman: *L. Reis* ) | |
| 9.00h | Plenary: **P. T. Castro** - Fatigue of Aircraft (Chairman: *M. Abdelaziz* ) | |
| | Chairman: *M. Abdelaziz* | Chairman: *Y. Matvienko* |
| 9.40h | **V. Anes** - Magnesium alloy elastoplastic behaviour under multiaxial loading conditions | **Chul-Su Kim** - Study on Parameter Sensitive Analysis of Braking Shoe Shape |
| 10.00h | **Y. Kudryavtsev** - Measurement of Residual Stresses and Fatigue Analysis of Welded Elements | **Ivan Čular** - Numerical Bending Fatigue Analysis of a Surface Hardened Spur Gears |
| 10.20h | **Li-Sha Niu** - Fretting fatigue damage analysis for Ni-based single crystal superalloy | **R. Marat** - Experimental and Numerical Characterization of Stress-Strain Fields on Sandwich Beams Subjected to 3PB and 4PB |
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| 11.30h | **J. Papuga** - Parameters affecting the response to non-proportional fatigue loading | **F.J.P. Moreira** - Numerical analysis of bonded joints by the extended finite element method |
| 11.50h | **G. Almaraz** - Fatigue tests on the proton exchange membrane Nafion 115 of fuel cells, under the biaxial modality: tension and torsion | **B. Albuquerque** - Characterization and Evaluation of a Cork Agglomerate Under Different Strain Rates Towards Aeronautical Applications |
| 12.10h | **O. Plekhov** - The Effect of Fatigue Crack Rate on the Heat Dissipation in Metals under Mix Mode Loading | **R. Campilho** - Asymmetric tapered double-cantilever beam specimen to predict mixed-mode fracture of structural adhesives |
| 12.30h | **F. Castro** - Fatigue behavior of grade U2 steel used in a reduced-scale mooring chain testing machine | **M. Vieira** - Computational Modelling of a Monopile Foundation for Offshore Wind Turbine |
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| | Chairman: *PT Castro* | Chairman: *L. Milovic* |
| 14.40h | **A. Hassanirad** - Experimental Fatigue Rig for Testing Structural Elements | **Young -Hak Huh** - Comparison of TTP Creep Models for Creep Rupture Life Prediction of Boiler Tube |

| | | | |
|---|---|---|---|
| 15.00h | **Jun-Hyub Park** - Study on Load Sequence Effect in Fatigue Strength Assessment of Thin Film using Copper Films | | **Bojana Aleksic** - Determination of Polynomial Depending Between Hardness and Cooling Time Δt8/5 of Steel Nionicral 70 Heat affected Zone |
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| 16.30h | **F. Canut** - Monitoring of Corrosion-Fatigue Degradation of Steel Using an Electrochemical-Mechanical Approach | | **Ricardo Ambriz** - Experimental and numerical approach on the impact behavior of aluminum welds |
| 16.50h | **K. Majchrowicz** - Stress corrosion cracking testing of P110 steel in CO2 containing environments | | **B. V. Farahani** - Experimental and Numerical Elastoplasticity and Fracture Mechanics - Review |
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| 17.30h | **M.E.Djeghlal** - Electrochemical Behavior of Corrosion on Borided and Non-Borided Steels Immersed in Acid Solution | | **M. Hadj Meliani** - Interaction Rules for a Colony of External Corrosion Defects Using Finite Element Analysis on API 5L Pipe Steel |
| 18.00h | **Welcome reception - Hotel Roof top** | | |

| **Day 2 - Thursday - 19th July** | | | |
|---|---|---|---|
| **Time** | **Room Açores** | | **Room Navegadores** |
| 8.30h | Reception/Registration | | |
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| | Chairman: *M. Freitas* | | Chairman: *F. Vaz* |
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| 10.00h | **Yuri Kudryavtsev** - Fatigue Improvement of Welded Elements by Ultrasonic Peening | | **M. Piska** - Progressive milling technologies, surface quality and fatigue properties of the aluminum alloy 7475-T7351 |
| 10.20h | **Hiroko Mikado** - Effect of WC grain size and Co content on the short surface fatigue crack growth characteristics of the WC/Co cemented carbid | | **E. Madenci** - Peridynamic modeling of impact damage in laminated composites |
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## *Materials Sessions*



## *Corrosion Sessions*



## *Fracture Sessions*

# Determination of Polynomial Depending Between Hardness and Cooling Time Δt8/5 of Steel Nionicral 70 Heat affected Zone

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**Abstract** Because of the high heating and cooling velocity values, welding procedure is an unstable process. During welding, changes in microstructure are occurring under overheating and/or cooling conditions. In comparing to the parent steel (PM), throughout welding of steel alloys, a whole series of complex processes are performed which influence to the appearance of different weldments microstructure and at the level of stresses in the weld metal (WM) and the heat-affected zone (HAZ). In present paper, the analytic dependence between Vickers hardness (HV) values and cooling time in temperature interval from 800 ºC to 500 ºC (Δt8/5) will be determined using the test results of experimental investigation of NIONICRAL 70 (NN-70) steel.

***Keywords**:* HSLA steel, HAZ, hardness, cooling time Δt8/5

## 1. Introduction

Due to the high values of heating and cooling speed, welding is a non-equilibrium process, and all changes in microstructure that occur during welding, develop in overheating or undercooling conditions. At the locations of the joint formation during welding of steel by melting, a whole series of simple and complex processes develop, causing the appearance of differences in the microstructure and the level of stresses in the welded joint (WJ) constituents, weld metal (WM) and heat-affected zone (HAZ), comparing to the parent material (PM) [1]. The mechanical properties of the overall WJ depend on the properties of PM, WM and HAZ. These properties depend on the microstructure of certain parts of the WJ determined by the chemical composition, the thermal cycle of welding and the previous, or subsequent thermal treatment. The chemical composition of WM depends on the share of the parent and filler metal in the WM and the interaction of metals, slag and gases. Depending on the interaction of these relevant factors, the WM strength may be at the level of the strength of the PM (mismatching), higher (overmatching) or bellow (undermatching) the level of the strength of the PM. [2-4]. The welding procedure significantly affects the WM properties since the WM microstructure and chemical composition as well depend on them. The share of PM in the WM depends on the welding procedure specification (WPS), and this ratio may vary from 15 to 80% [5]. The thermal welding cycle represented by a continuous cooling transformation (CCT) diagram, Figure 1, is the basic criterion for estimation of the influence of parameters of the welding procedure on the modification of the microstructure in the PM, Fig. 2, subjected to the thermal effect during welding, and therefore to the variation of hardness in the HAZ.

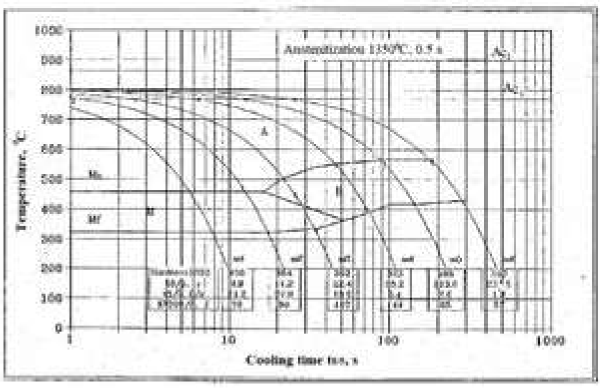


**Figure 1**: CCT diagram of steel NN-70 [6]

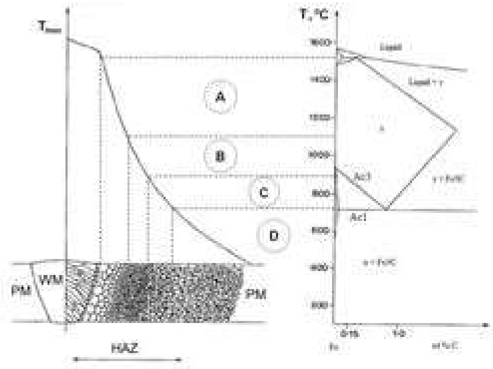



**Figure 2:** Heterogeneity of structures in heat-affected zone for single-pass welding [7,8], A – Coarse grain HAZ (CGHAZ), B – Fine grain HAZ (FGHAZ), C – Intercritical HAZ (ICHAZ), D – Subcritical HAZ (SCHAZ)

Regarding the properties of the WJ, one of the biggest problems is the variation in the metallurgical and mechanical properties in the HAZ, that is, the drop-in plasticity in the HAZ, which is directly related to the increase of hardness or decrease of cooling time Δt8/5.

## 2. Materials and methods

### *2.1. HAZ Thermal Simulation of Samples*

For the simulation of the HAZ, steel NN-70, the Yugoslav version of the American steel HY-100, was used. The chemical composition and mechanical properties of the steel NN-70 are given in Tables 1 and 2.

**Table 1:** Chemical composition of as-rolled NN-70 steel, wt %

| 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 |
| **Cu** | **Ti** | **Nb** | **As** | **Sn** | **W** | **Sb** | **Ta** | **Co** | **N** |
| 0.246 | 0.002 | 0.007 | 0.017 | 0.014 | 0.0109 | 0.007 | 0.0009 | 0.0189 | 0.0096 |

**Table 2:** Mechanical properties of NN-70 steel

| Material | $E$, GPa | $R_m$, MPa | $R_{p0.2}$, MPa | $A_5$, % | HV30 | $E_{tot}$, J | $E_i$, J | $E_p$, J |
|---|---|---|---|---|---|---|---|---|
| PM | 209 | 860 | 809 | 28.6 | 245-269 | 96.83 | 39.6 | 57.23 |

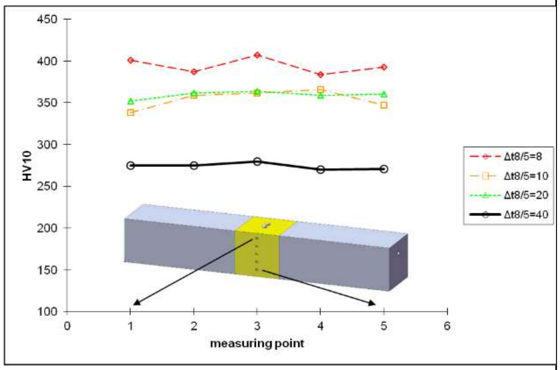
Standard Charpy specimens (11x11x 60 mm) and fatigue specimens (11x11x90 mm) [9], were simulated on thermal cycle simulator Smitweld 1405 Fig. 3a. Thermal cycles were achieved by electro-resistant heating according to a given timing plan, controlled using a photocell by monitoring of the given cooling curve, Fig. 3b. Through the specimen, predetermined and adjusted heating current was passed until the specimen was heated up to the maximum temperature. The jaws in which the sample was held were cooled with water, and the sample itself was cooled with an inert gas stream.

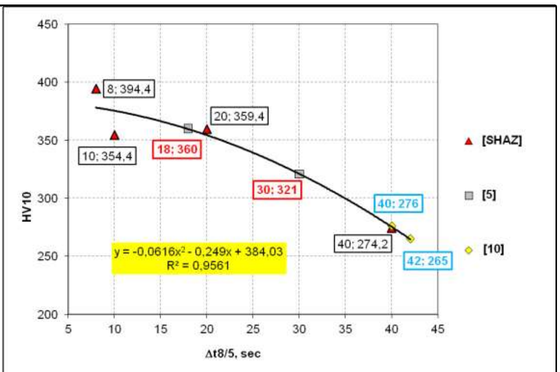

*a. Thermal cycle simulator Smitweld 1405* *b. Scheme of HAZ simulation*

*Figure 3. Thermal simulation of HAZ on samples of NN-70 steel [2, 9]*

Samples were exposed for 0.5 s to the austenitization temperature of 1300 °C for different cooling times ($\Delta t8/5$ = 8, 10, 20 and 40 s), in order to obtain the microstructure and properties of the materials that approximately correspond to those of HAZ of NN-70 steel, formed in conditions of different welding regimes [5, 10].

**Table 3:** The results of hardness measurement of simulated HAZ and real HAZ of NN-70 steel and their polynomial dependence




| Measuring point | 1 | 2 | 3 | 4 | 5 | Average value | mm |
|---|---|---|---|---|---|---|---|
| $\Delta t_{8/5}$, s | 1.5 | 3.5 | 5.5 | 7.5 | 9.5 | | |
| **8** | 401 | 387 | 407 | 384 | 393 | 394.4 | HV10 |
| **10** | 338 | 359 | 362 | 366 | 347 | 354.4 | HV10 |
| **20** | 352 | 362 | 364 | 359 | 360 | 359.4 | HV10 |
| **40** | 275 | 275 | 280 | 270 | 271 | 274.2 | HV10 |
| Measured in previous studies [5, 10] | | | | | | | |
| **18** | [5] | | | | | 360 | HV30 |
| **30** | | | | | | 321 | HV30 |
| **40** | [10] | | | | | 276 | HV10 |
| **42** | | | | | | 265 | HV10 |

The samples of the simulated HAZ were tested for hardness, HV 10. The results of the measured hardness on the samples of the simulated HAZ were compared with the results of the hardness of the real HAZ measured in previous studies [5, 10], that have been taken in this paper. On the basis of the measured and taken data [5, 10], Tab. 3, the polynomial dependence of the variation in hardness HV10, and cooling time $\Delta t8/5$ was determined and shown in the diagram in Tab. 3.

## 3. Conclusions

Based on the selection of hardness in HAZ of the NN-70 welded joint, the diagram of the polynomial dependence of the variation of hardness HV10 and cooling time $\Delta t_{8/5}$, allows us to choose the appropriate HAZ plasticity, which requires a corresponding welded microstructure with a controlled cooling time. The samples of simulated HAZ with cooling time of $\Delta t_{8/5} = 40$ s have the highest value of impact energy, and therefore this regime was selected for the thermal simulation of all experimental samples used in this study [12-15].

## Acknowledgements

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## References

[1] Vidojević N.: Strukturne promene uz metal šava pri zavarivanju čelika topljenjem, Zavarivanje i zavarene konstrukcije, vol.45, br.3, 2000, str. 115-118.

[2] Milović Lj. Analiza integriteta zavarenih komponenata procesne opreme za povišene radne temperature, doktorska disertacija, Mašinski fakultet Univerziteta u Beogradu, 2008.
[3] Schwalbe K.H, Zerbst U, Brocks W, Cornec A, Heerens J, Amstutz H. The ETM method for assessing the significance of crack-like defects in engineering structures. Fatigue&Fracture of Engineering Materials&Structures 1998; 21: 1215-1231.
[4] Aleksić B., Aleksić V., Milović Lj.: Analysis of the effects of butt welded joints on a carrying capacity of a structure tank, journal Materials Protection 58 (4), 462 - 468 (2017).
[5] Grabulov V.: Prilog definisanju uticaja hemijskog sastava i debljine lima na pojavu prskotina u zavarenim spojevima čelika Nionikral-70, magistarski rad, Tehnološko – metalurški fakulktet Univerziteta u Beogradu, 1986.
[6] Odanović Z.: Numeričko modeliranje toplotnog režima procesa elektrolučnog zavarivanja čelika i predvidjanje mogućih efekata na zonu uticaja toplote, Doktorska disertacija, Tehnološko-metalurški fakultet, Beograd,1993.
[7] Akselsen O.M.: Transformation Behaviour, NTNU, Trondheim, Norway, 2012, p. 15.1-15.19.
[8] Stridsklev C.A.: Sulfide Stress Corrosion Cracking Resistance of Modified ASTM A694 F60 Low Alloy Steel for Subsea Application, Master thesis, Norvegian University of Science and Technology, Department of Materials Science and Engineering, Trondheim, Norway, 2013.
[9] Aleksic V.: Niskociklični zamor niskolegiranih čelika povišene čvrstoće, radna verzija prijavljene doktorske disertacije, Tehnološko-metalurški fakultet Univerziteta u Beogradu, 2018.
[10] Bulatovic S.: Elasto-plastično ponašanje zavarenog spoja od niskolegiranog čelika povišene čvrstoće u uslovima niskocikličnog zamora, Doktorska disertacija, Mašinski fakultet Univerziteta u Beogradu, 2014.
[11] Aleksic V., Dojčinović M., Milovic Lj., Samardžić I.: Cavitation damages morphology of high-strength low-alloy steel, METALURGIJA, (2016), vol. 55 br. 3, 423-425.
[12] Aleksić V., Aleksić B., Milović Lj.: Methodology for determining the region of stabiliyation of low-cycle fatigue, Book of Abstracts, 16th International Conference on New Trends in Fatigue and Fracture (NT2F16), May 24-27, 2016, Dubrovnik, Croatia, 189 – 190.
[13] Aleksić V., Milović Lj., Aleksić B., Abubkr M. Hemer: Indicators of HSLA steel behavior under low cycle fatigue loading, 21st European Conference on Fracture, ECF21, 20-24 June 2016, Catania, Italy, Procedia Structural Integrity 2 (2016) 3313–3321.
[14] Aleksić V., Milović Lj., Aleksić B., Bulatović S., Burzić Z., Hemer M. A.: Behaviour of Nionikral-70 in low-cycle fatigue, journal Structural integrity and life, Vol.17, br. 1, 2017, 61-73.
[15] Aleksić B., Aleksić V., Hemer M. A., Milović Lj., Grbović A.: Determination of the region of stabilization on low-cycle fatigue HSLA steel from test data, Proceedings of the 17th International Conference on New, Trends in Fatigue and Fracture (NT2F17), October 25-27th, 2017, Cancun, Mexico, 101-112.

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*The organizing committee*

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