Resistance of the welded joint of austenitic steel NEUTRONIT A 976 SM in the corrosive environment of boric acid

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The paper deals with the influence of the operating environment on the safe resistance of the welded joint of the construction material used in the nuclear power industry in the production of spent nuclear fuel containers. This material contains a higher percentage of alloying boron and is used as a shielding construction material for neutron and gamma radiation. It is used to produce baskets for spent nuclear fuel containers. When the containers are being filled, the welded joint of the basket structure are briefly exposed to an aqueous boric acid solution. The aim of this work was to determine the effects of exposure to the corrosive boric acid environment on the mechanical properties of the material. Tensile tests on the original weld and post weld exposure in H_3BO_3 and corrosion cracking tests on unexposed welds were performed. The evaluation of the results revealed that the exposure to the corrosive environment of boric acid did not significantly affect the strength characteristics of the tested material NEUTRONIT A 976 SM.

INTRODUCTION

The assessed material is Neutronit A 976 SM. It is an austenitic stainless steel alloyed with boron. This steel is one of the main construction materials used in nuclear energy as a shielding material for neutron and gamma radiation. This type of material is used in containers for the transport and dry storage of spent nuclear fuel and aims to reduce the flux of neutron and gamma radiation. In addition, this stainless steel exhibits excellent structural and mechanical stability at the elevated temperatures that can occur when using dry spent fuel storage. When filling the container with burnt fuel rods, this material is exposed to short-term exposure to an aqueous solution of boric acid [1-3].

EXPERIMENTAL

Weld analyses were performed on NEUTRONIT A 976 SM. This is an austenitic steel alloyed with boron with the following chemical composition and with the stated mechanical properties, see Tables 1 and 2.

The analyzed material was in the form of a sheet, in which the weld was made by laser welding, without additional welding material. The test specimens were manufactured by the method of Electrical Discharged Machining (EDM) – electroerosive wire cutting, see Figure 1. During the production of the test specimens, the weld was preserved in the original quality, ie it was not ground, polished or otherwise modified.



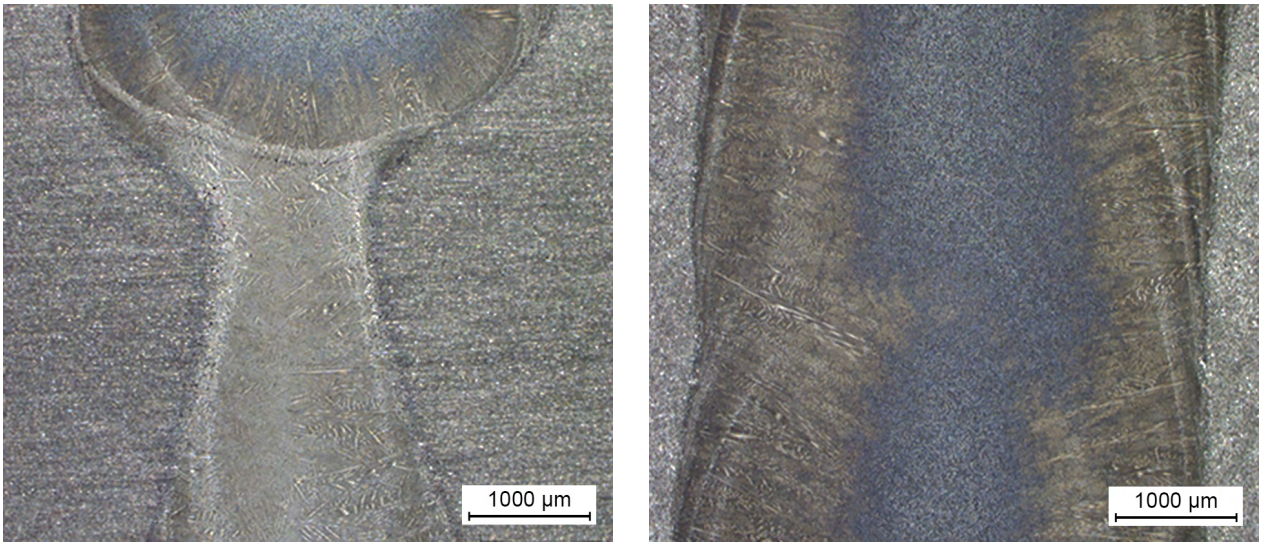
Fig. 1. Test specimens

Tab. 2. Mechanical properties of NEUTRONIT A 976 SM

$Rp_{0,2}$ [MPa]	R_m [MPa]
250	550-750

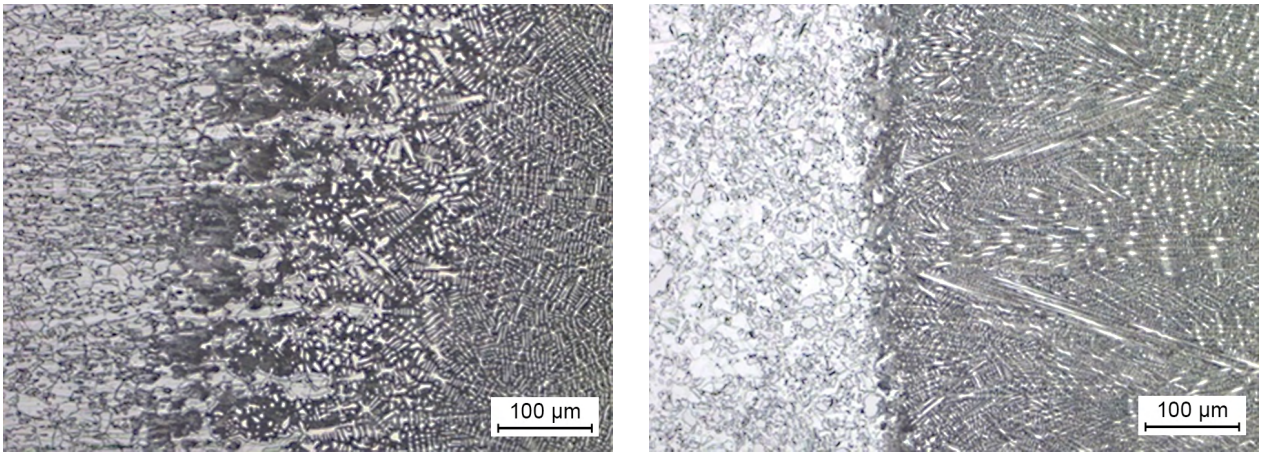
Tab. 1. Chemical composition of NEUTRONIT A 976 SM

	C	Si	Mn	P	S	Cr	Ni	Co	B
% w	0.021	0.34	1.08	0.02	0.0003	19.27	12.73	0.05	1.15



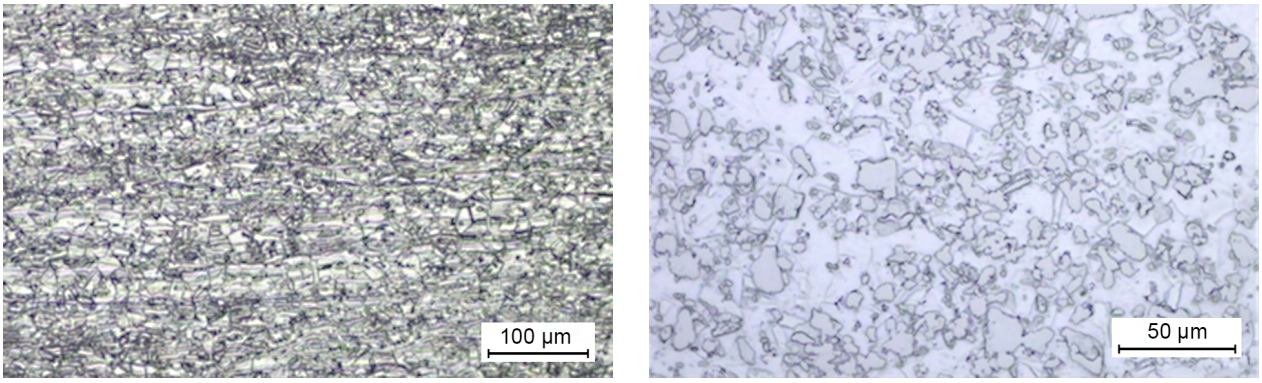
a) b)

Fig. 2. Macrostructure of the test specimen weld: a) cross section, b) longitudinal section



a) b)

Fig. 3. Microstructure TOO: a) cross section, b) longitudinal section



a) b)

Fig. 4. Microstructure of the base material: a) cross section, b) longitudinal section

The basic material consists of an austenitic structure with regularly distributed boride particles with a size of tens of µm. The heat affected zone (THA) at the interface of the weld metal and the base material is formed by regions with a fine-grained and coarse-grained structure, which transition to a dendritic structure of the weld metal. The width of the THA is in the range of 100-150 µm. The weld metal contains austenitic dendrites with a boride eutectic in the interdendritic space. An example of a macrostructure and a microstructure in longitudinal and transverse section is shown in Figs. 2-4.

RESULTS AND DISCUSSION

Tensile test at constant strain rate

The test specimens were divided into several sets according to the test environment and parameters, see Tab. 3.

A portion of the test specimens was first exposed in a 375 g l^{-1} H_3BO_3 solution for 750 hours at 100 °C to achieve extreme material loading conditions beyond the operating conditions to which the material is exposed. To determine the ground state, the test specimens were tested in air in tension at a constant strain rate.

Sample sets for corrosion cracking tests were equipped with a silicone flow cell in which the corrosion medium flowed. The constant temperature of the corrosion medium was maintained by means of an apparatus consisting of a heating nest and a thermostat, see Figure 5. Circulation of the medium was ensured by a peristaltic pump.



Fig. 5. Apparatus for testing in a corrosive environment

A universal electromechanical testing machine Zwick-Roell Z250, with a maximum force capacity of 250 kN was used to perform tensile tests.

Figure 6 shows graphical courses of tensile tests for individual sets and mutual comparison of tensile strength limits. Sets 1 (strain rate 10^{-3} s^{-1}, RT, after exposure) and 2 (strain rate 10^{-3} s^{-1}, RT) have comparable values of tensile strength limits. Exposure to 750 hours in H_3BO_3 does not affect the strength characteristics of the weld under investigation. Set 3 (strain rate 10^{-6} s^{-1}, 20 °C in 1.15 % H_3BO_3 environment) has comparable values of tensile strength limits with sets 1 and 2. Set 4 (strain rate 10^{-6} s^{-1}, 95 °C in an environment of 22 % H_3BO_3) has lower values of tensile strength due to increased temperature. The environment does not affect the strength characteristics of the welded joint.

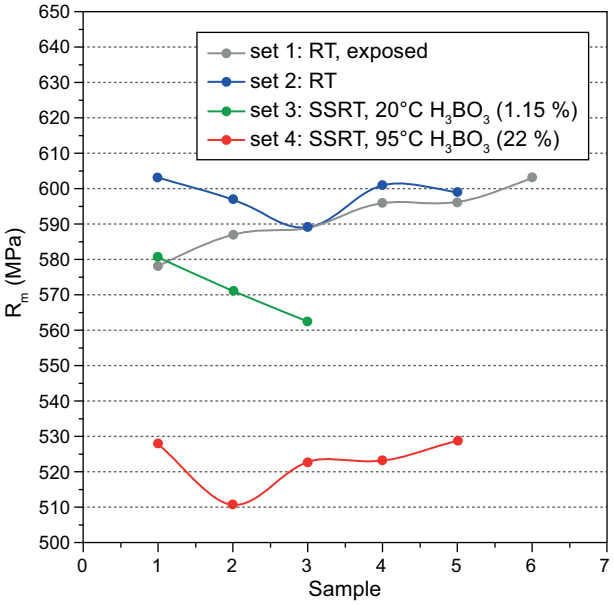


Fig. 6. Graphical courses of tensile tests for individual sets and mutual comparison of tensile strength limits

Figure 7 summarizes the total deformations, i.e. the elongation of the test body measured through the cross member, including both elastic and plastic deformation. Based on a test body length of 75 mm, a change in elongation of 1 mm corresponds to approximately

Tab. 3. Overview of test parameters of individual sets of samples

Set	Test temperature [°C]	Exposure	Environment	Deformation rate [s^{-1}]	Standards
1	23 ± 5	H_3BO_3 (750 hours/100°C)	air	10^{-3}	ISO 6892
2	23 ± 5	without exposure	air	10^{-3}	ISO 6892
3	20	without exposure	1.15% H_3BO_3	10^{-6}	ISO 75 394
4	95	without exposure	1.15% H_3BO_3	10^{-6}	ISO 75 394

1.3 % deformation. Sets 1 (strain rate 10^{-3} s^{-1}, RT, after exposure) and 2 (strain rate 10^{-3} s^{-1}, RT) have comparable elongation. Exposure of 750 hours in H_3BO_3 does not affect the ductility of the examined weld. The elongation is comparable for set 3 (deformation rate 10^{-6} s^{-1}, 20 °C in the environment of 1.15 % H_3BO_3). The effect of speed and environment on set 3 is negligible. Set 4 (deformation rate 10^{-6} s^{-1}, 95 °C in 22 % H_3BO_3 environment) had less elongation compared to the other sets. Lower ductility is caused by a combination of temperature and environmental influences.

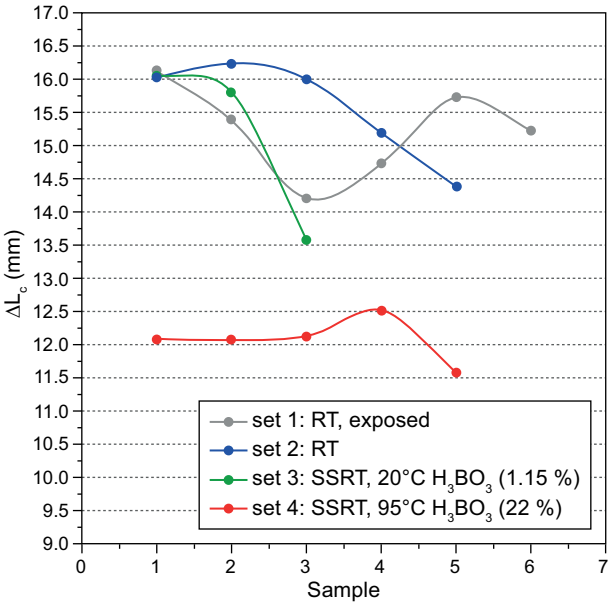


Fig. 7. Comparison of total deformations of samples in performed tensile tests

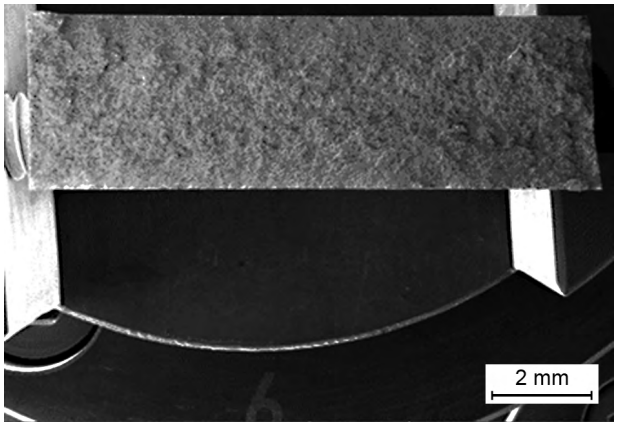
Fractographic evaluation of quarry areas

Fractography of fracture surfaces was evaluated using a Mira 3 GMU Scanning Electron Microscope (SEM), in SE and BSE observation mode. The fracture surfaces of the test specimen were analyzed in the initial state, see Figure 8 and the test body, see Figure 9 after testing in extreme corrosive environments.

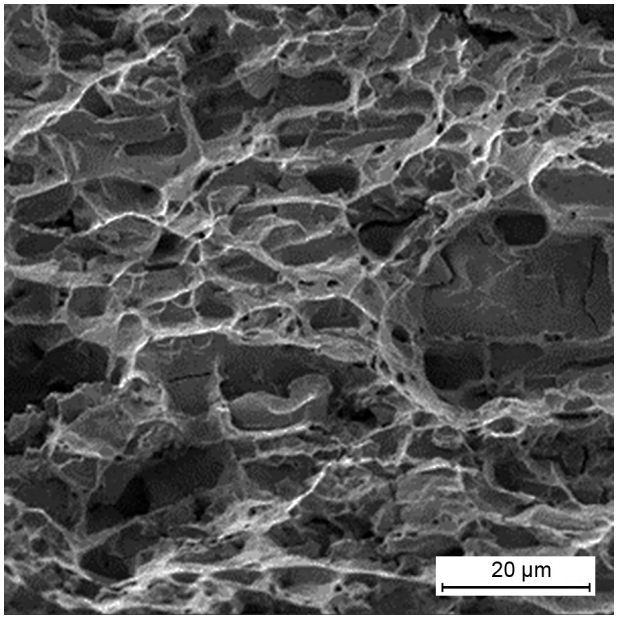
The fracture surfaces after the tensile test show predominantly ductile transcrystalline failure with a hole-like morphology with areas of fission failure in the form of intercrystalline facets. Fission disruption occurs in boride particles. Corrosion cracking is not evident in the test specimen even after loading in a corrosive environment at elevated temperatures.

CONCLUSION

A laser-welded sheet of NEUTRONIT A 976 SM was used for the given tests. The basic material consists of an austenitic structure with regularly distributed boride particles with a size of tens of μm. The heat-affected region at the interface of the weld metal and the base material is formed by regions with a fine-grained and coarse-grained structure, which merge into a dendritic structure of the weld metal. Test specimens were made from the assessed material, which were divided into 4 sets according to the test environment and parameters. Set 1 was exposed in 375 g l^{-1} H_3BO_3 solution for 750 hours at 100 °C, which simulated extreme material loading conditions. To determine the initial state, the test specimens were tested in air in tension at a constant strain rate. Sets of samples for corrosion cracking tests were equipped with a silicone flow cell in which a corrosion medium of a given concentration and temperature flowed. The results of tensile tests show that the exposure of the test specimens in a 375 g l^{-1} H_3BO_3 solution for 750 hours at 100 °C does not affect the strength characteristics of the weld under investigation.

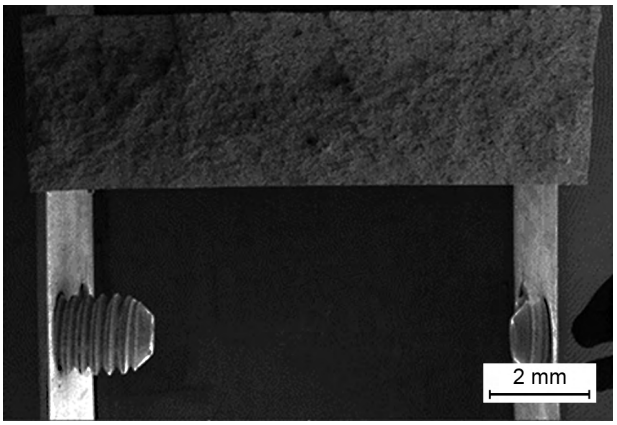


a)

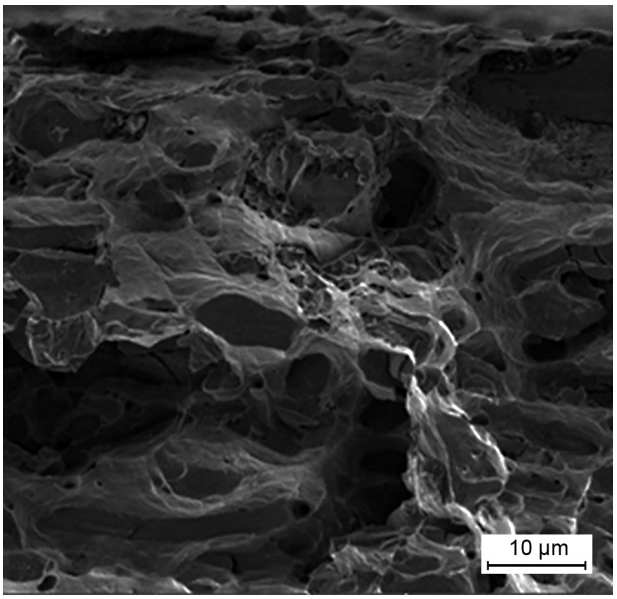


b)

Fig. 8. Fracture surfaces of the test specimen in the initial state: a) macro view, b) edge of the fracture surface



a)



b)

Fig. 9. Fracture surfaces of the test specimen after the test in an extreme corrosive environment: a) macro view, b) edge of the fracture surface

Sets 1, 2 and 3 have comparable values of tensile and elongation limits. Set 4 (corrosive and temperature effects) shows lower strength and ductility. The fracture surfaces after the tensile test of all test specimens show predominantly ductile transcrystalline failure with a hole-like morphology with areas of fission failure in the form of intercrystalline facets. Fission disruption occurs in boride particles. The fractographic evaluation of the test specimen after the test in an environment at elevated temperatures did not show the influence of the corrosion medium and the lower ductility is mainly caused by the influence of temperature.

Acknowledgement

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