UDC 622.873

INFLUENCE OF POST-WELDING PROCESSING ON CONTINUOUS CORROSION RATE AND MICROSTRUCTURE OF WELDED JOINTS OF STEEL 20 AND 30KHGSA

Andrei M. SCHIPACHEV[1], **Sergei V. GORBACHEV**[2]
[1] *Saint-Petersburg Mining University, Saint-Petersburg, Russia*
[2] *Orenburg State University, Orenburg, Russia*

Welded joints of structure steels have lower corrosion resistance in comparison to base metal. To increase corrosion resistance of welded joints and heat-affected zone they use longtime and energy-consuming methods of thermal and mechanic processing.

The article covers the possibility of using the superplasticity deformation (SD) effect for processing of welded joints. The effect of SD is that metals and alloys with a small grain size (of the order of 10 μm) under conditions of isothermal deformation at a certain temperature acquire the ability for unusually large plastic deformations while reducing the deformation resistance. Grain-boundary sliding during superplasticity provides a high degree of structural homogeneity. If the metal does not have the small grain size, then during isothermal deformation at appropriate temperature the SD effect will not be fully manifested but will cause relaxation of residual micro and macro strains, recrystallization, which can be used during processing of welded joints to ensure their full strength.

There have been carried out the investigation of processing methods impact - SD, thermal cycling and influence of post-welding treatment on corrosion rate and microstructure of steels 20 and 30KhGSA. It is shown that after deformation in superplasticity mode there is low corrosion rate and more favorable microstructure in the studied samples of steel. Post-welding processing of welded joints in SD mode provides low tool loads and low energy costs.

Key words: welded joint, corrosion rate, microstructure, deformation in superplasticity mode, steels 20 and 30KhGSA, thermal cycling treatment

How to cite this article: Schipachev A.M., Gorbachev S.V. Influence of Post-welding Processing on Continuous Corrosion Rate and Microstructure of Welded Joints of Steel 20 and 30KhGSA. Journal of Mining Institute. 2018. Vol. 231, p. 307-311. DOI: 10.25515/PMI.2018.3.307

Introduction. Welded joints of structural steels have less corrosion resistance than the base metal. The issues of ensuring full strength of welded joints with welded structural steels are covered in many scientific studies, and their results find practical application [6, 8-11]. To improve the corrosion resistance of the welded seam and heat-affected zone, thermomechanical processing methods [1, 12, 13, 15, 16] are used, which are longtime and energy-intensive. In this regard the application of plastic deformation method in the super-plasticity mode is of immediate interest.

Superplastic deformation (SD) of metals was discovered and investigated by A.A. Bochvar et al. [14]. Extensive experimental studies and practical introduction of their results were carried out at the Institute for Metals Superplasticity Problems of Russian Academy of Sciences [14]. The effect of SD is that metals and alloys with a small grain size (of the order of 10 μm) under conditions of isothermal deformation at a certain temperature acquire the ability for unusually large plastic deformations (of the order of 10^2-10^3 %) while reducing the deformation resistance.

When deformed at optimal temperature and velocity conditions of superplasticity, the shape of the grains, despite the elongation or compression, does not change significantly, they remain equiaxed [7]. It is established that the effect of superplasticity is manifested in carbon steels with the structure of granular perlite [14]. With deformation in the superplasticity mode of steel 45, the dispersity of the structure increases: both ferritic and perlite grains are reduced in size, the thickness of cementitious plates decreases and distance between them decreases, and secondary carbides and carbonitrides are significantly ground and redistributed.

The deformation in the temperature and velocity conditions of superplasticity has long been used to improve the quality of welded joints, to obtain a more uniform structural state in the heat-affected zone, and to reduce residual stresses [2]. If the metal does not have such a small grain size, then under an isothermal deformation at the appropriate temperature, the SD effect will not be fully manifested in it, however, as the authors suggest, it will cause relaxation of residual micro- and macrostresses, recrystallization, which can be used to affect welded joints to ensure their full strength.

The corrosion rates and microstructure parameters for steel samples 20 and 30KhGSA were compared after application of this method and thermomechanical processing, annealing and in the absence of post-welding processing.

Experimental technique. Isothermal cogging with heated rolls of samples of welded joints was carried out with deformation rates of 10, 20 and 40 % at a temperature of 730 ± 5 °C, which is the optimum temperature of SD for structural steels with a constant strain rate of $0.003\ s^{-1}$. Cogging was carried out on a laboratory six-roll mill LIS-6/200 of the Institute for Metal Superplasticity Problems of Russian Academy of Sciences, the isothermal conditions of deformation were provided by heating working rolls and their temperature regulation.

For comparison, the method of thermal cycling treatment (TCT) of welded joints was chosen. Samples were heated to a temperature of 880 °C and held at an upper heating stage temperature for 5 minutes. Then they were transferred to a furnace pre-heated to a temperature of 730 °C and exposed there for 5 minutes. The number of cycles was from 2 to 15, after that the samples were cooled in air. For comparative studies of the effect of thermal cycling and deformation in the SD mode, we used samples after two processing cycles, since they have commensurate time for post-welding treatment as compared to deformation treatment.

In carrying out studies of annealing effect and determining the role of superplastic deformation on structure and mechanical properties of welded joints, the samples were placed in a tubular electric resistance furnace, which was heated to a temperature of 730 °C. Thermoelectric thermometers were used to monitor the temperature regime. The samples were held at a predetermined temperature for 30; 60; 180; 300 and 600 min followed by air cooling.

Discussion of results. Evaluation of welded joint samples resistance and base metal against continuous corrosion in the medium (5 % sodium chloride NaCl + 0.5 % acetic acid CH_3COOH) saturated with gaseous hydrogen sulfide to a concentration of 2.8 g/l, pH 3.15, was carried out by gravimetric method [4]. The results of welded samples corrosion rate changes in relation to exposure time are shown in Fig.1-4.

Annealing, thermal cycling treatment and deformation in the superplasticity mode of welded joints of steel 20 can equally reduce the rate of continuous corrosion of welded joints in the hydrogen sulfide medium to the level of the base metal (Fig.1, 2).

The corrosion rate of welded steel samples of 30KhGSA unprocessed welded joints exceeds the corrosion rate of the base metal by 17 % (Fig.3, 4). Further processing of welded joints allows to reduce the rate of corrosion to the level of the base metal, with the best results observed when annealing and cogging by rollers in the SD mode. The difference between the corrosion rate relative to the base metal reaches 3-6 %. Thermocycling does not significantly affect the reduction in corrosion rate, which is explained by the increase of hardness in the heat-affected region.

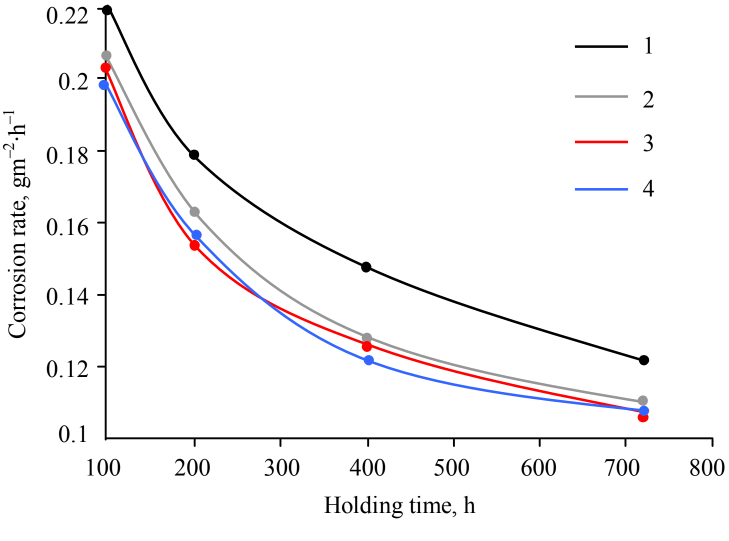

Fig.1. Dependence of corrosion rate of welded joints of steel 20 from holding time in corrosive environment

1 – initial welded joint; 2 – TCT; 3 – deformation in SD mode – 20 %; 4 – annealing

Metallographic studies of the microstructure of the welded joint of steel 20 [3] were carried out. The welded joint metal of steel 20 in the initial state (without post-welding processing) consists of ferrite and perlite, its microstructure is characterized by a dendritic structure of grains oriented along the direction of heat dissipation from the weld pool upon cooling.

The average grain size in the welded joint metal in the initial state is 12 µm, in the thermal impact zone the average grain size varies from 6 µm for the fine grains to 9 µm in the superheating section (Fig. 5). In this case, coarse grains up to 48 µm in size appear.

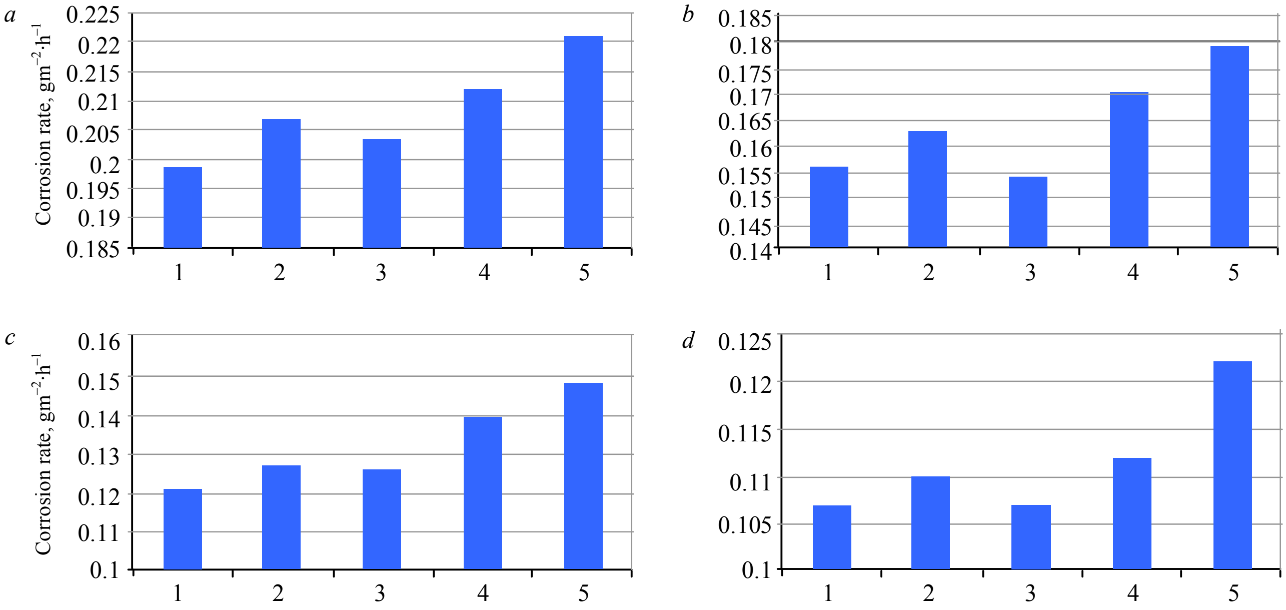

Fig.2. Changes of corrosion rate of welded joints of steel 20 as a result of post-welding processing:
a – holding time 96 h; *b* – 200 h; *c* – 400 h; *d* – 720 h
1 – annealing; 2 – TCT; 3 – deformation in SD mode – 20 %; 4 – base metal; 5 – initial welded joint

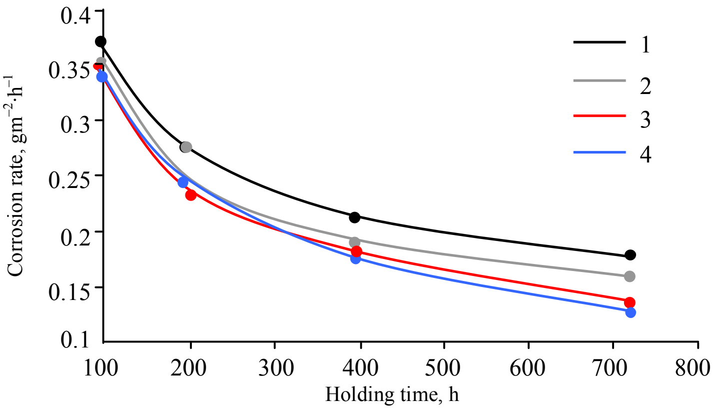

Fig.3. Dependence of corrosion rate of welded joints of steel 30 KhGSA from holding time in corrosive environment
1 – initial welded joint; 2 – TCT;
3 – deformation in SD mode – 20 %; 4 – annealing

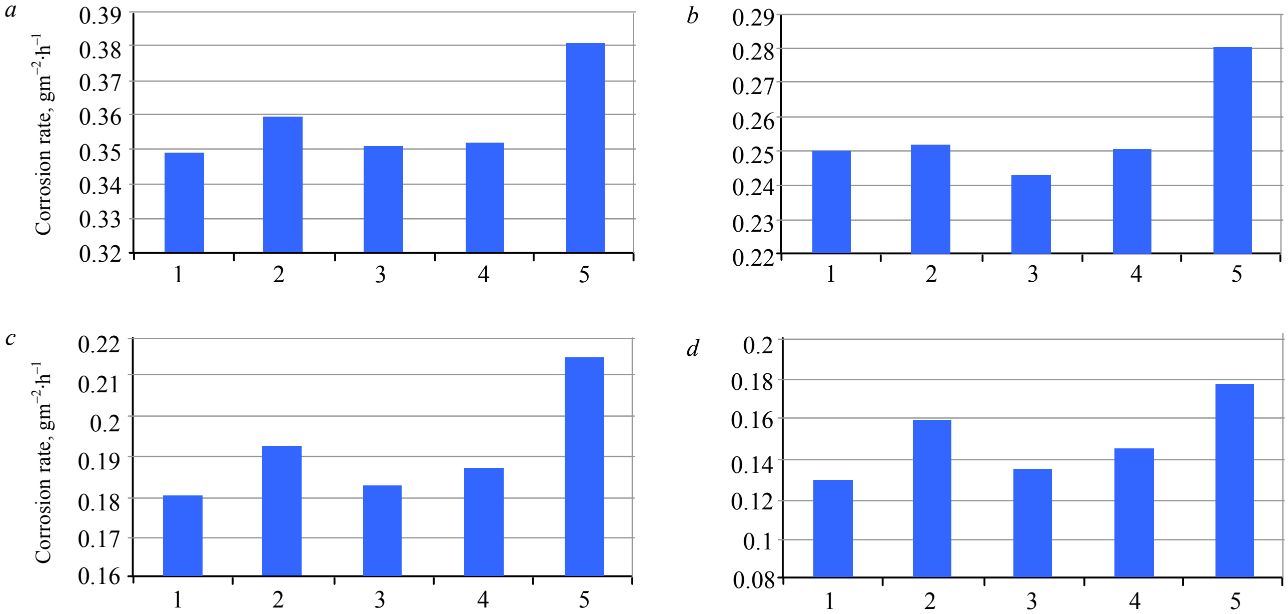

Fig. 4. Change of corrosion rate of welded joints of steel 30KhGSA as a result of post-welding processing:
a – holding time 96 h; *b* – 200 h; *c* – 400 h; *d* – 720 h
1 – annealing; 2 – TCT; 3 – deformation in SD mode – 20 %; 4 – base metal; 5 – initial welded joint

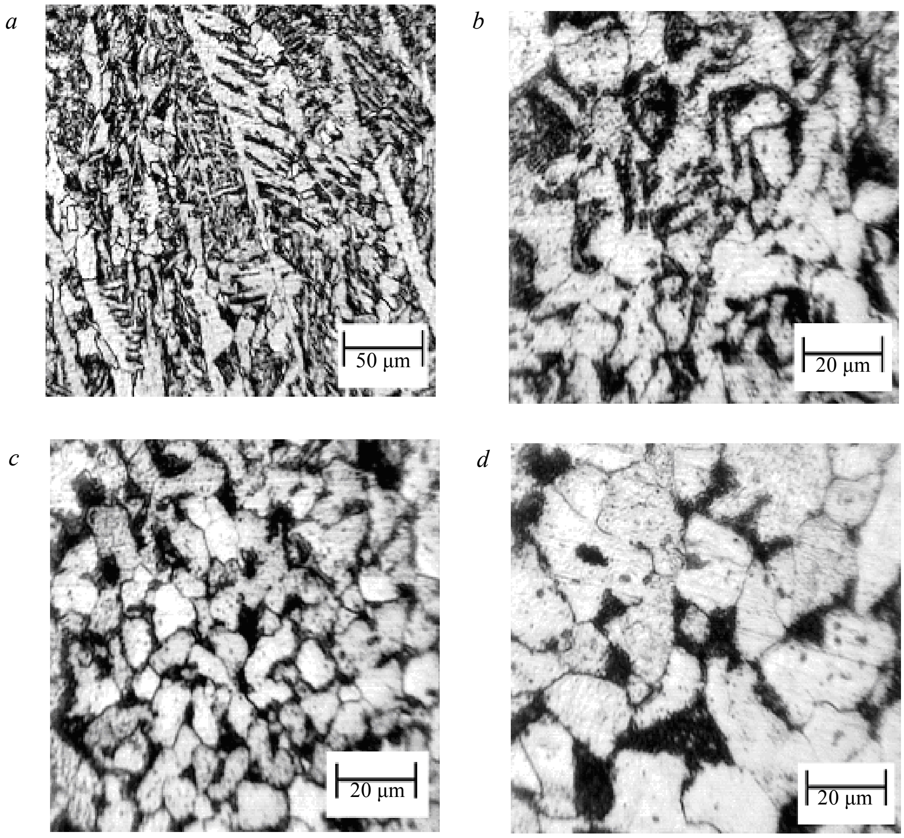

Fig.5. Microstructure of welded joint sample of steel 20 before processing:
a – a section of welded joint; *b* – coarse grain TIZ; *c* – fine grain TIZ; *d* – base metal

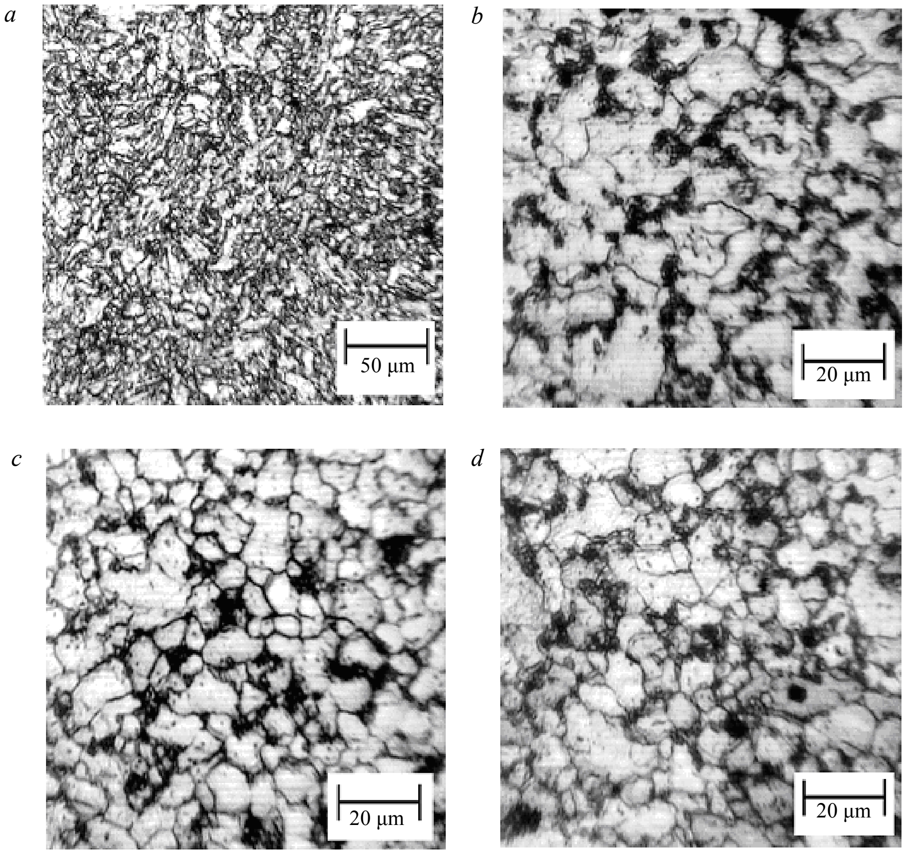

Fig.6. Microstructure of welded joint sample of steel 20 after deformation in SD mode:
a – a section of welded joint; *b* – coarse grain TIZ; *c* – fine grain TIZ; *d* – base metal

After cogging by heated rolls in the SD mode, the average grain size decreases both in the base metal and in the heat-affected zone (Fig.6). As a result, the average grain size in these zones of the welded joint after cogging in the SD mode is from 7 to 8 μm.

Conclusions. The use of hot plastic deformation for processing of welded joints in the temperature-velocity modes of superplasticity allows to ensure their structural homogeneity, as well as a combination of high strength and plasticity. Processing of welded joints in the superplastic deformation mode (SD) provides low energy costs and high production efficiency.

Energy-saving modes of welded joints processing allow to reduce the heterogeneity of mechanical properties and increase the reliability of welded joints of pipelines, parts and structures of petrochemical equipment.

REFERENCES

1. Abdeev R.G., Zolotushkin I.V., Petrov K.V. Feasibility of additional processing of welded joints after repair of pipelines. Sovremennye tekhnologii v neftegazovom dele; UGNTN. Ufa, 2017, p. 95-98 (in Russian).

2. Gorbachev S.V., Fot A.P., Shchipachev A.M., Lutfullin R.Ya. Influence of post-welding processing on structural features of welded joints of steels 20 and 30KhGSA. Vestnik Orenburgskogo gosudarstvennogo universiteta. 2015. N 4, p. 159-164 (in Russian).

3. Gorbachev S.V., Shchipachev A.M., Lutfullin R.Ya. Investigation of the heterogeneity in the deformation-heat processing of welded joints of steel 20. *Neftegazovoe delo: elektronnyi nauchnyi zhurnal*. 2014. N 1, p. 302-316. URL: http://www.ogbus.ru/authors/Gorbachev/Gorbachev (in Russian).

4. Gorbachev S.V. Increase in the homogeneity of the structure and mechanical properties of welded joints from steels 20 and 30KhGSA in the superplastic deformation mode: Avtoref. dis.…kand. tekhn. nauk; UGNTU. Ufa, 2005, p.20 (in Russian).

5. Gulyaev A.P., Sarmanova L.M. High-temperature plasticity of carbon steels. *Metallovedenie i termicheskaya obrabotka metallov*. 1972. N 4, p. 43 (in Russian).

6. Il'inykh A.S., Galai M.S., Sidorov E.S. Investigation of welded rail joints after machining at different post-welding temperature. *Obrabotka metallov* (*tekhnologiya, oborudovanie, instrumenty*). 2017. N 3 (76), p. 28-34 (in Russian).

7. Kaibyshev O.A., Utyashev F.Z. Superplasticity, grinding of structure and processing of hard-deformable alloys. Moscow: Nauka, 2002, p. 438 (in Russian).

8. Korol'kov P.M. nfluence of local heat treatment on the properties of welded joints of technological pipelines of small diameters of steel 20. *Svarochnoe proizvodstvo*. 1993. N 11-12, p. 9-12 (in Russian).

9. Korol'kov P.M. Performance of welded joints of thin-walled pipelines of steel 20 in corrosive environments. *Svarochnoe proizvodstvo*. 1991. N 4, p. 13-15 (in Russian).

10. Parshukov L.I., Gil'mutdinov F.Z., Skupov A.A. Investigation of welded joints of martensitizing steel of type 03N18K9M5T after local thermal cycling. Trudy VIAM. 2017. N 7 (55), p. 55-60 (in Russian).

11. Andersen P., Duguette D. Slow strain rate Stress Corrosion Testing at Elevated Temperatures and High Pressures. *Corrosion Science*. 1980. Vol. 20, p. 211-223.

12. Ivanov A.Yu., Sulyagin R.V., Orlov V.V., Kruglova F.F. Formation of structure in the heat-affected zone and properties of welded joinrs of pipe steels of strength classes X80 and X90. *Met. Science*. 2012. Vol. 53. N 11, p. 560-566.

13. Goli-Oglu E.A. Influence of heat treatment after welding on the microhardness of steel joints in marine platforms. *Steel in Translation*. 2016. Vol. 46. Iss. 5, p. 361-363.

14. Mulyukov R.R., Nazarov A.A., Imayev R.M. Current status of research and development on superplasticity at the Institute for Metals Superplasticity Problems. *Mater. Sci. Forum*. 2013. Vol. 735, p. 403-408.

15. Taniguchi G., Yamashita K. Effects of post weld heat treatment (PWHT) temperature of mechanical properties of weld metals for high-Cr ferritic heat-resistant steel. *Kobelko Technology Review*. 2013. N 32, p. 33-39.

16. Tavares S.S., Rodriges C.R., Pardal J.M. Effects of post weld heat treatments on the microstructure and mechanical properties of dissimilar weld of supermartensitic Stainless steel. *Materials Reseach*. 2014. Vol. 17(5), p. 1336-1343.

Authors**: Andrei M. Schipachev,** *Doctor of Engineering Sciences*, *Professor*, *Schipachev_AM@pers.spmi.ru* (*Saint-Petersburg Mining University*, *Saint-Petersburg*, *Russia*), **Sergei V. Gorbachev**, *Candidate of Engineering Sciences*, *Associate Professor*, *trf12@mail.osu.ru* (*Orenburg State University*, *Orenburg*, *Russia*).

The paper was received on 25 June, *2017.*
The paper was accepted for publication on 10 May, *2018.*