Thermal treatment of dissimilar steels' welded joints

A A Nikulina, A S Denisova, I N Gradusov, P A Ryabinkina and M V Rushkovets
Novosibirsk State Technical University, 20, K. Marks ave., Novosibirsk, 630073, Russia
E-mail: a.nikulina@corp.nstu.ru

Abstract. In this paper combinations of chrome-nickel steel and high-carbon steel, produced by flash butt welding after heat treatment, are investigated. Light and electron microscopic studies show that the welded joints after heat treatment have a complex structure consisting of several phases as initial welded joints. A martensite structure in welded joints after thermal treatment at 300...800 °C has been found.

1. Introduction
The aim of heat treatment of welded joints is to change the structure, the phase composition and the stress state of the material. It may include various types of thermal influence, and the main features of the process will be determined by the structure of steels before welding, the weld metal composition, the purpose of the structure and the conditions of its operation [1]. When similar steels are welded, thermal treatment allows changing the structure of the heat affected zone and the weld, resulting in increased reliability. In the case of dissimilar steels welding the possibility of using heat treatment is limited, as it can lead to an unequal or even opposite effect in welded steels [1–4].

One of the most common combinations in the composite structure is a combination of austenitic and pearlitic steels. An example is a railway frog, which is welded with the rail by means of a layer of austenitic chromium-nickel steel allowing to combine the welding conditions of austenitic steel, included into the structure of the crossbar, and the pearlite rail steel [5]. A construction consisting of dissimilar steels is performed by flash butt contact welding. Although stainless steel allows forming the weld seam between chromium-nickel and carbon steels, its fracture toughness will be low [5, 6].

As thermal treatment is one of the ways to improve the reliability of welded joints, the aim of this work was to study the structural transformations occurring during heat treatment of the welds between the pearlite and high-chromium-nickel austenitic steels obtained by flash butt welding.

2. Materials and methods
The chemical composition of base steels is given in table 1. Samples of the welded joints were cut perpendicularly to the plane of joining. Thermal treatment of welded joints was carried out in furnace SNOL 7.2/1300 at the temperatures of 300...1000 °C. After heating to the temperatures of 300...800 °C samples were cooled in the air, and after heating to 1000 °C – in the furnace. Structural investigations were carried out using the Carl Zeiss Axio Observer Z1m light microscope and scanning electron microscope Carl Zeiss EVO 50XVP. Microhardness measurements were taken by the Wolpert Group 402MVD tester.
### Table 1. Chemical composition of steels (wt %).

| Steel              | C    | Mn  | Si  | Cr | Ni | Ti | P    | S    |
|--------------------|------|-----|-----|----|----|----|------|------|
| High-carbon steel  | 0.72 | 0.78| 0.14| –  | –  | –  | 0.020| 0.012|
| Chrome-nickel steel| 0.11 | 0.58| 0.53| 17.1| 9.7| 0.38| 0.021| 0.012|

### 3. Result and discussion

The investigated steels are dissimilar and, in addition to the differences in the chemical composition, they also have different initial structures. The welds of these steels obtained by flash butt welding are characterized by considerable heterogeneity and the presence of high-strength areas. Their formation is a result of mechanical agitation of the welded materials and diffusion processes. This leads to the formation of local areas with a low content of alloying elements compared with the initial chrome-nickel steel, which is confirmed by the EDS analysis (Figure 1a). When the weld cools, the low alloyed areas gain an austenitic-martensitic structure (Figure 1b). The microhardness of these areas is on average 600 HV, whereas the level of the initial microhardness of steels does not exceed 250…300 HV. The width of such weld is approximately 1000 μm. The martensitic areas reduce significantly fracture toughness of welded compositions ‘high carbon steel – chrome-nickel steel’, because either they or their boundaries are preferred places for crack propagation [6].

![Figure 1](image_url)

**Figure 1.** A general view of the weld in the initial state with the distribution of elements (a) and local alloyed area (b). P – pearlite, A – austenite, M – martensite.

After tempering at temperatures of 300…500 °C major structural changes in the welds are not observed: areas having austenitic-martensitic structure are preserved (Figure 2), and their microhardness corresponds to the initial state. The width of the weld does not change either.

Heating of welds to a temperature of 800 °C results in substantial changes in the structure of samples under investigation. The width of the weld increases up to 1200…1800 μm, and ferrite and ferrite-pearlite areas appear as well (Figure 3a). This is due to the diffusion process, which actively takes place at high temperatures. However, the austenitic-martensitic zones are also present (Figure 3b). The presence of areas with the reduced content of alloying elements compared with the initial chrome-nickel steel was confirmed by the EDS-analysis of welded joints (Figure 4). However, this temperature was not enough to significantly reduce the concentration of alloying elements in these areas and cooling leads to the formation of the martensitic structure with maintaining a substantial fraction of the residual austenite at the same time. Microhardness of the ferrite layer is equal to 150 HV, and the level of microhardness of the adjacent layer which has a ferrite-pearlite structure is 260 HV. The hardness of the martensitic-austenitic regions varies from 350 to 700 HV. Such deviations in the microhardness level of martensite are caused by the difference in the chemical composition of the austenite microvolumes from which it was formed.
After heating at 1000 °C samples were cooled by the furnace. Such heat treatment leads to a significant change in the structure of welded joints (Figure 5a). Active diffusion causes increasing of the weld width, and finally it can reach 5000 μm. The structure of the weld from the carbon steel part is characterized by a successive ferrite and then ferrite-pearlite structure with localized austenitic areas. On the other side of the visible boundary austenite grains were observed with dense carbide mesh (Figure 5b).

![Figure 2](image1.png)

**Figure 2.** A general view of the welded joint (a) and the local austenitic-martensitic area (b) after tempering at 400 °C.

![Figure 3](image2.png)

**Figure 3.** A general view of the welded joint (a) and the local zone after thermal treatment at 800 °C (b). P – pearlite, A – austenite, M – martensite, F – ferrite.

Metallographic studies showed the absence of martensite in the weld after its annealing. The level of microhardness of the weld is characterized by significant heterogeneity, and the range of its changing even increases: microhardness of the ferrite layer is 150 HV and microhardness of carbides formed (Figure 6) reaches 800 HV (Figure 7). The presence of the ferrite layer with low hardness and strength in the weld is undesirable because it leads to decreasing in weld strength and reduction of its service life due to fatigue spalling of the ferrite layers [7]. A carbide network in the weld is also an unfavorable factor and may lead to premature failure of welded constructions [1]. Using of low-carbon barrier layers can be an alternative to heat treatment in order to decrease martensite hardness formed in the welding process [8].
4. Conclusions
Structural studies and microhardness evaluation results indicate that heat treatment at temperatures of 300…500 °C does not lead to significant changes in the structure of the welds. Areas with the austenitic-martensitic structure are present, and their microhardness corresponds to the original state before heat treatment. A martensitic structure is also formed in the weld zone and after heat treatment at 800 °C. In general, the thickness of the weld increases from 1000 to 1800 μm. Microhardness of austenitic-martensitic areas depends on the initial chemical composition of austenite and varies from 350 to 700 HV.

Active diffusion during heat treatment at 1000 °C leads to an increase of the width of the weld up to 5000 μm.

![Image](image.png)

**Figure 4.** Line distribution of chemical elements perpendicularly to the welded joint:

- **a** – a general view;
- **b** – at the visible border of steels.

![Image](image.png)

**Figure 5.** A general view (a) and a visible border of steels (b) after thermal treatment at 1000 °C.

The range of the microhardness level becomes even wider as microhardness of carbides formed reaches 800 HV, and the adjacent ferrite layer is only 150 HV. Thus, heat treatment of welded joints of austenitic chromium-nickel steel and pearlite carbon is not suitable.

**Acknowledgement**
The authors gratefully acknowledge the financial support from the Russian Ministry of Education and Science (research task No.2014/138, project 257).
Figure 6. Carbides in localized alloyed areas after heat treatment at 1000 °C (a) and microhardness of the welded joint (b): 1 – after heat treatment at 1000 °C, 2 – initial state.

References
[1] Olson D L, Siewert T A, Liu S, Edwards G R 1993 Welding, Brazing, and Soldering ASM Handbook vol 6 (Asm International) p 873
[2] Robert W and Messler Jr 2004 Joining of Materials and Structures (Burlington: Elsevier) p 815
[3] Dawson K E, Tatlock G J, Chi K and Barnard P 2013 Changes in precipitate distributions and the microstructural evolution of P24/P91 dissimilar metal welds during PWHT Metallurgical and materials transactions A 44A 5065–80
[4] Falat L, Ciripová L, Kepic J, Buršík J and Podstranská I 2014 Correlation between microstructure and creep performance of martensitic/austenitic transition weldment in dependence of its post-weld heat treatment Engineering Failure Analysis 40 141
[5] Zhang F, Lv B, Hu B and Li. Y 2007 Flash butt welding of high manganese steel crossing and carbon steel rail Mater. Sci. Eng. A 454–455 288
[6] Nikulina A A, Bataev A A, Smirnov A I, Popelyukh A I, Burov V G and Veselov S V 2015 Microstructure and fracture behaviour of flash butt welds between dissimilar steels Science and Technology of Welding and Joining 20 138
[7] Ed Lewis R, Olofsson U 2009 Wheel/rail interface handbook (Cambridge: Woodhead publ Ltd) p 864
[8] Chevakinskaya A A, Nikulina A A and Plotnikova N V 2015 Reliability increase of dissimilar steel welded joints Applied Mechanics and Materials 698 378