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Influence of Structure of Welded Connections from a Heat Resistant Steel on their Reliability

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Welded connections of steels 08X25T and 20X23H18 GOST 5632-72 (X8CrTi25 and X20CrNi23-18 under the standard EN100027-1 and CR 10260) were investigated. The welding was conducted by a manual way (111 LST EN 24063) using constant current of return polarity and covered electrodes. The main difficulty at welding of high-alloy heat-resistant steel is large deformations also an opportunity of a formation of cracks in a seam and adjacent to it zone. The formation of cracks can be caused by defects of welded seam, presence of hardened structure in a welded zone, saturation of metal of a seam by hydrogen, and internal stresses due to shrinkage of a metal of the seam. It is established, that the least reliability of welded seams is observed in the case of martensitic structure of a seam, and the greatest – in the case of an austenitic structure.

Keywords: welded joints, heat-resistant steels.

1. INTRODUCTION

Reliability can be characterized as property of a construction to keep its quality for a rather long time [1]. Besides it is important to know beforehand the non-failure probability or the resource of a construction. Also it is important to know, how the construction losses its serviceability. The emergency destruction occurs, when one or several unfavorable factors arise. For example, if the fragile hardened structure was formed in a welded seam, or there are cracks in a seam, a sudden (emergency) destruction of a construction can take place at a shock type or variable loading. The main difficulty of welding of heat-resistant nickel-chromium steel and chromium steel is their propersity to form hot and cold cracks in the seem also in the fusion zone. The hot cracks more often have an intercrystalline character. They can be observed as smallest microcracks, as well as seen cracks. Formation of the hot cracks is usually related to the formation of the coarse grain structure in the seam at welding and presence of stresses due to the shrinkage [2 – 7, 10].

The cold cracks usually develop on the cold-short mechanism and are directed into the lengthways or across in a welded seam. Their occurrence is related with infringements of welding technology and is caused by three reasons: by the presence of hardened structure in a zone of high temperature heating during welding; by saturation of a metal by hydrogen (as a result of usage of nonhardened welding materials at welding); by presence of concentrators of stresses of technological and structural types (welding defects such as slag inclusions, incomplete fusions, cuts and others, also zones of sharp transition in a welded construction). The probability of occurrence of cold cracks grows with increasing of thickness of welded details [3 – 5, 8 – 10].

Using various welding electrodes there are chemical, structural and mechanical heterogeneities in welded connections. At long operation of welding connections of such steels at high temperature in the fusion zone the structure can change and structural heterogeneity can form. The change of structure of metal of a seam can be so strong, that its static and cyclic durability and plasticity essentially will decrease.

The mechanical properties of welded connections of alloyed steels appreciably depend on structural and chemical heterogeneity of the fusion zone. The heterogeneity is represented as a carbonless layer in a low alloyed metal and high carbon layer in an alloyed metal. The formation of these layers is the result of diffusion of a carbon from less alloyed metal to more alloyed, caused by distinction of thermodynamic activity of this element in both layers [3 – 5].

Already during welding there is a non-uniform distribution of carbon in a fusion zone: spasmodic increasing of the content of carbon in a seam metal, also formation of microchemical heterogeneity in the form of a carbide grid. It reduces mechanical properties of the welding zone. The development of microchemical heterogeneity essentially depends on a regime and conditions of welding. It is recommended to use moderate regimes for reducing of carbon diffusion in a fusion zone [3 – 5]. If it is necessary to use more productive forced regimes, that should be combined with methods reducing a share of the basic metal in a seam.

The purpose of the given work was to establish the structure of welded joints of a heat resistant steel using manual welding by different electrodes and to estimate approximately the reliability of these connections.

2. EXPERIMENTAL

Materials for realization of complex researches in a metal science field were templets, which were cut out from seams of the welded plates. A comparative metalographics

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analysis of a seam metal and a metal of a zone near to the seem, obtained by manual arc welding (111 EN 24063) of plates (200 × 100 × 6 mm) from steel 08X25T and 20X23H18 GOST 5632-72 (X8CrTi25 and X20CrNi23-18 according to the standard EN100027-1 and CR 10260), was carried out. Pearlitic electrodes UONI -13/45 (EN 499 - E46 3 B4H10), austenitic electrodes OZL-6 (ISO 3581: E 25.13B), austenitic-ferritic electrodes UTP-65D (EN 1600: E29 9 R/2), nickel electrodes UTP-068HH (EN 1736: EL- NiCr19Nb) and copper electrodes UTP 34N (EN 1733: EL- CuMn14Al) were applied. The welding was conducted at a constant current of return polarity in one pass by electrodes of a diameter 3.0 and 3.2 mm. The current of welding was 110 A, voltage of an arch was 22 – 24 V. The structure of a seam was investigated using a microscope LEICA MEF 4M and scanning electron microscope XL 30 ESEM, PHILIPS. Chemical composition was determined by a microscope Spectro LAB 05 3/N 45/263. The chemical structure of the basic and welding materials is presented in the Table 1.

3. RESULTS AND ANALYSIS

The comparative analysis of microstructure of metal of the seam and of the zone near to the seam were carried out at welding of heat-resistant steels. The chemical structure at the centre of the cross section of the welded seam determined with the help of a scanning electron microscope XL 30 ESEM, PHILIPS, is given in Table 2.

To estimate reliability of a welded connection it is very important to know its strength and a character of a possible destruction. Martensite has high hardness and durability, also small plasticity. In the case of a martensitic structure of a welded joint, and when upper limit of loading takes place, there can be fast fragile destruction. It is especially dangerous at shock or variable loading. In this case the reliability of a construction will be low and it can be used only at static loading. An austenite has smaller durability and high plasticity. At presence of an austenitic structure in a welded joint and when an upper limit of loading is used, a slow (viscous) destruction takes place more often.

Microstructures of a fusion zone and fracturegrams of a surface of the destroyed seam received at welding steels 08X25T and 20X23H18 GOST 5632-72 (X8CrTi25 and X20CrNi23-18 under the standard EN100027-1 and CR 10260) using various electrodes are presented in Fig. 1 – 5.

The structure of a welded metal can be determined by using the Sheffler diagram (Fig. 6) taken average values Ni and Cr [4]:

$$Ni_{eq} = \text{of } \%\, Ni + 30\,\% \times C + 0.5\,\% \times Mn. \qquad (1)$$

$$Cr_{eq} = \text{of } \%\, Cr + \%\, Mo + 1.5\,\% \times Si + 0.5\,\% \times Nb. \qquad (2)$$

Using the Sheffler diagram (Fig. 6) for the determination of the phase composition of the weld in the case of welding carbon steel with an austenitic one, we can see that the structure contains 90 % of an austenite and 10 % of ferrite. The martensite in this case is entirely excluded. Therefore it may be expected that the formation of cracks in the weld metal is nearly impossible when the weld is formed by welding different metals using austenitic electrodes. By the way, in practice during the welding of an austenitic steel with carbon steel in the weld metal also in the fusion zone cracks sometimes appear.

At welding steel 20X23H18 by electrodes UONI-13/45 we have received: $Cr_{eq} = 13.17\,\%$; $Ni_{eq} = 11.53\,\%$; $Cr_{eq} / Ni_{eq} = 1.14$; $Cr_{eq} + Ni_{eq} = 24.70\,\% < 30\,\%$. In this case the structure of the seam should be martensitic, according to the Sheffler diagram – austenitic-martensitic. Structure of a fusion zone and fractograme of a surface of the seam destruction, presented in Fig. 1 show, that the seam has a complex austenitic-martensitic structure. The destruction of a seam occurs in a zone close to a fusion zone. Such seams can be used in designs, the operation temperature of which does not exceed 400 °C.

Table 1. Chemical structure of the basic and welding materials, %

Material	C	Mn	Si	Cr	Ni	Fe	The note
08X25T	0.08	0.63	0.41	26.71	-	71.34	Ti = 0.83
20X23H18	0.09	1.61	0.36	23.68	17.41	56.30	
UONI-13/45	0.10	0.35 – 0.60	0.03	0.15	0.30	98.7 – 99.0	
OZL-6	0.09	1.0 – 2.0	0.5 – 1.0	23.0 – 26.0	12.0 – 14.0	57.0 – 63.0	
UTP-65D	0.10	1.0	1.0	30	9.5	57-58.5	
UTP- 068HH	0.03	5.0	0.4	19	69	3	Mo = 1.5; Nb = 2.2
UTP-34N	0.03	13	-	-	2.5	2.5	Al = 7; Cu = 75

Table 2. Chemical structure of welded seams, %

Material	Electrode	Cr	Ni	Mn	Si	Fe
20X23 H18	UONI-13/45	12.51	8.17	1.32	0.44	77.56
20X23 H18	UTP-068HH	21.49	45.01	3.50	0.88	29.12
20X23 H18	UTP-034N	6.82	8.53	8.54	Al = 4.47	Cu = 54.39
08X25T	OZL-6	25.93	10.02	1.56	1.16	61.33
08X25T	UTP-65D	28.07	5.08	0.83	1.68	64.33

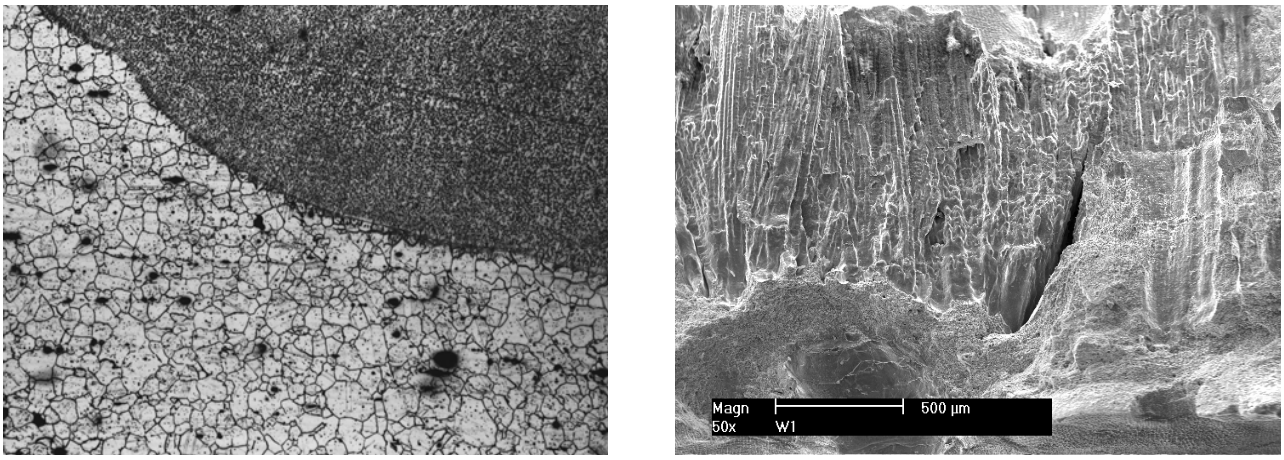

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Fig. 1. Structure of a fusion zone (a, ×200) and a fracturegram (b) of a welded seam received at welding steel 20X23H18 by electrodes UONI-13/45

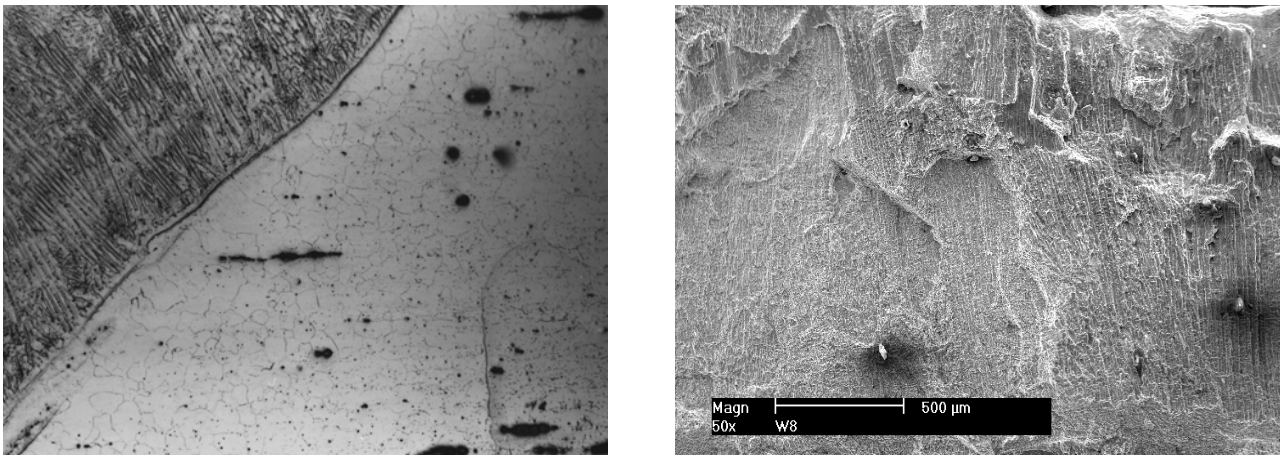

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Fig. 2. Structure of a fusion zone (a, ×200) and a fracturegram (b) of a welded seam obtained at welding steel 20X23H18 by nickel electrodes UTP-068HH

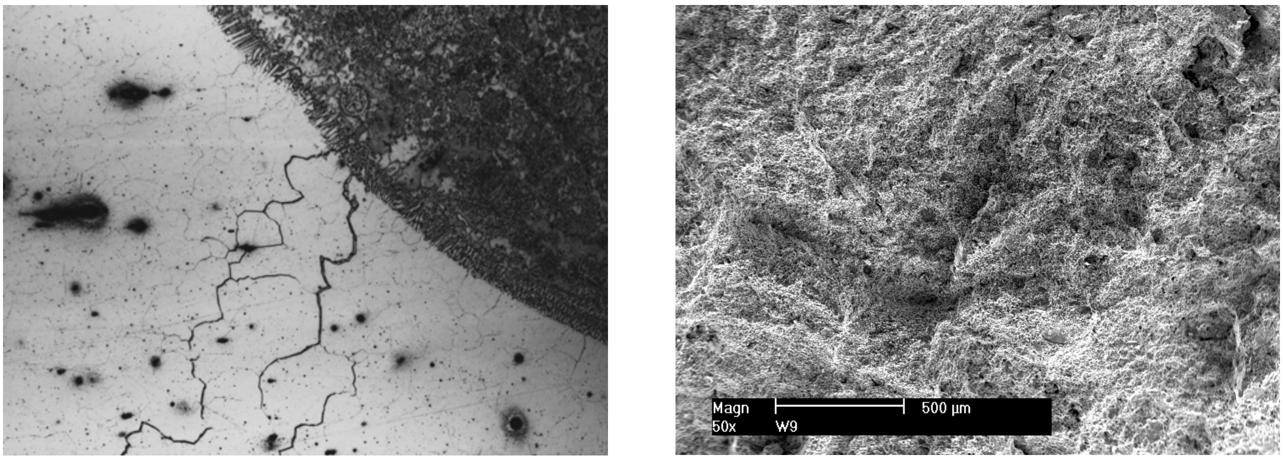

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Fig. 3. Structure of a fusion zone (a, ×200) and a fracturegram (b) of a welded seam received at welding steel 20X23H18 by copper electrodes UTP-34N

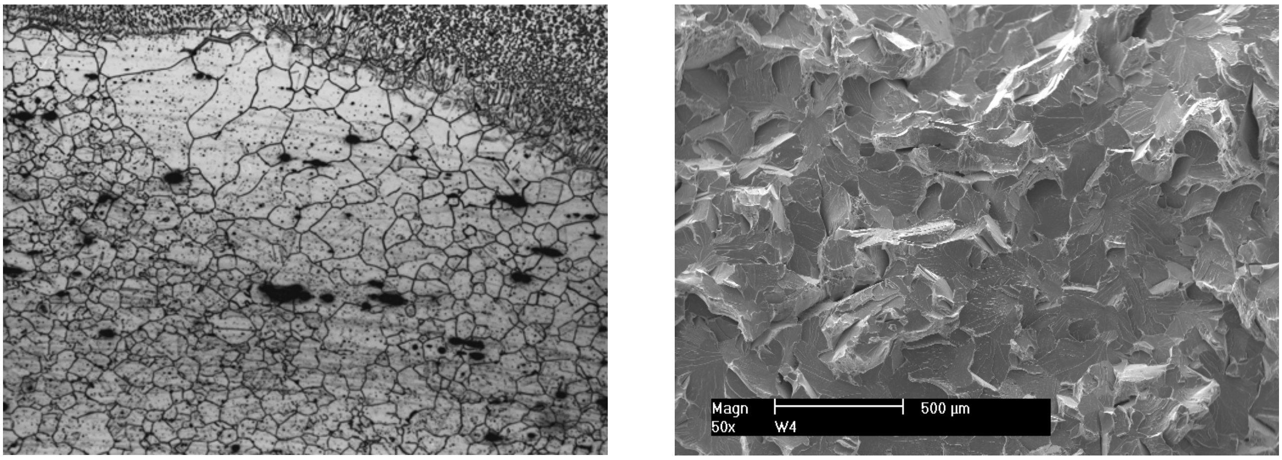

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Fig. 4. Structure of a fusion zone (a, ×200) and a fracturegram (b) of a welded seam received at welding steel 08X25T by austenitic electrodes OZL-6

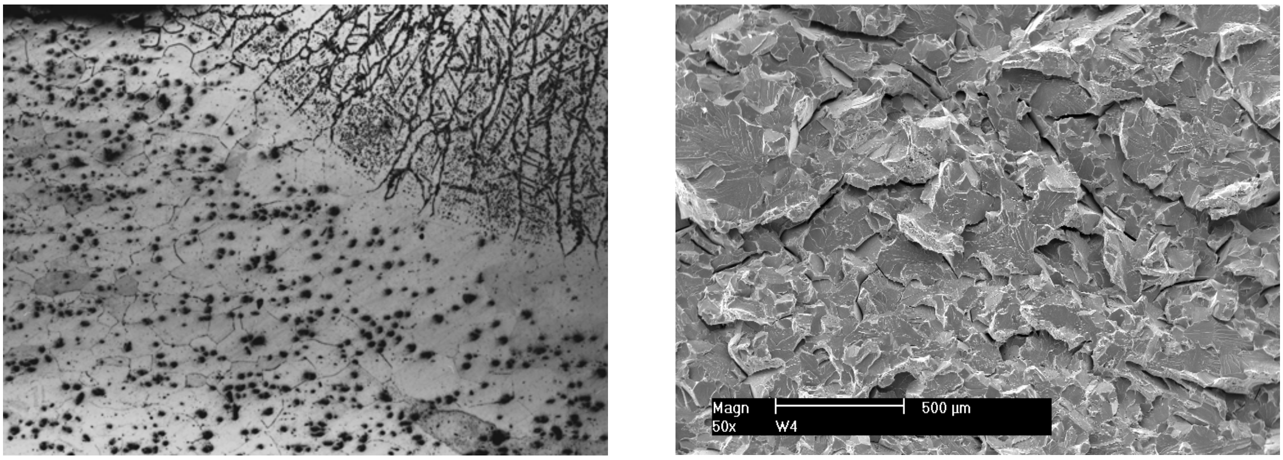

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Fig. 5. Structure of a fusion zone (a, ×200) and a fracturegram (b) of a welded seam received at welding steel 08X25T by austenitic-feritic electrodes UTP-65D

Table 3. The structure of a welded metal

Cr_{eq} / Ni_{eq}	$Cr_{eq} + Ni_{eq}$	Weld structure
< 2.5	< 30 %	martensitic structure
> 2.5	< 30 %	martensitic – ferritic structure
< 2.5	> 30 %	ferritic structure
1.25 – 2.5	> 30 %	austenitic – ferritic structure
< 1.25	> 30 %	austenitic structure

At welding steel 20X23H18 by electrodes UTP-068HH we have received: $Cr_{eq} = 22.81$ %; $Ni_{eq} = 49.46$ %; $Cr_{eq} / Ni_{eq} = 0.46$; $Cr_{eq} + Ni_{eq} = 72.27$ % > 30 %. The received data shows, that the seam has an austenitic structure only. Such seams can be exploited under any conditions. Structure of a fusion zone and a fracturegram of a destructions surface shown in Fig. 2, confirms it. The destruction of a seam occurs on its middle and has a viscous character.

It is also necessary to note, that electrodes UTP-068hh are the most expensive of the researched electrodes.

At welding steel 20X23H18 by electrodes UTP-034N we have received: $Cr_{eq} = 6.82$ %; $Ni_{eq} = 15.50$ %; $Cr_{eq} / Ni_{eq} = 0.44$; $Cr_{eq} + Ni_{eq} = 22.32$ % < 30 %. The received data show, that the seam has only the martensitic structure (according the Sheffler diagram – martensitic-ferritic). The presence of a plenty of copper and also aluminium creates in a seam various layers. During a crystallization process the martensitic transformation of a seam occurs. As the martensitic structure is bigger in volume, than austenitic one, increasing of already hardened seam takes place. Probably, it promotes bigger occurrence of cracks not only in a seam but also in a zone of the basic metal close to the seam. It is well visible in Fig. 3. The destruction of a seam occurs closer to a fusion zone. Therefore such electrodes for welding of austenitic steel could not be used.

At welding steel 08X25T by electrodes OZL-6 we have received $Cr_{eq} = 27.67$ %; $Ni_{eq} = 13.50$ %; $Cr_{eq} / Ni_{eq} = 1.83$; $Cr_{eq} + Ni_{eq} = 41.17$ % > 30 %. The received data show, that the structure of a seam should be ferritic (according the Sheffler diagram – austenitic-ferritic). Structure of a fusion zone and a fracturegram of the destroyed surface of the seam are presented in Fig. 4. It is visible, that the structure of a seam is close to martensitic-ferritic and a destruction is fragile and occurs in a fusion zone. Such seams can be used in the case of static loading.

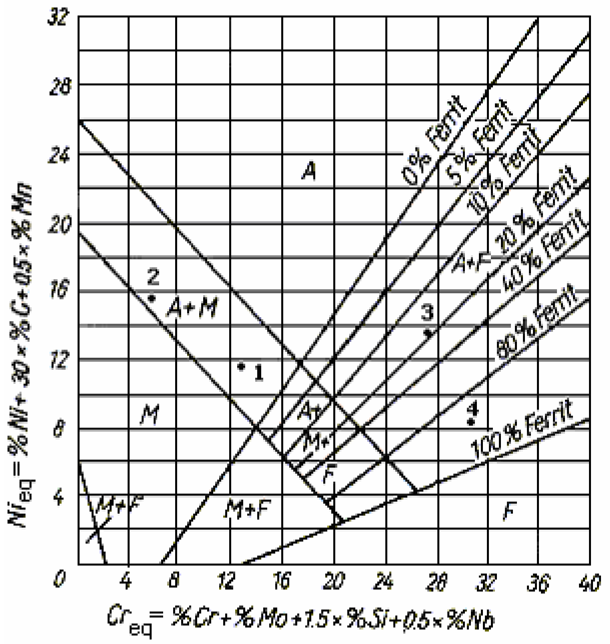

Fig. 6. Structures of welded seams on the diagram Sheffler. 1 – structure of a seam at welding steel 20X23H18 by electrodes UONI-13/45; 2 – structure of a seam at welding steel 20X23H18 by electrodes UTP-34N; 3 – structure of a seam at welding steel 08X25T by electrodes OZL-6; 4 – structure of a seam at welding steel 08X25T by electrodes UTP-65D [4]

At welding steel 08X25T by electrodes UTP-65D we have received $Cr_{eq} = 30.59$ %; $Ni_{eq} = 8.20$ %; $Cr_{eq} / Ni_{eq} = 3.73$; $Cr_{eq} + Ni_{eq} = 38.79 \% > 30 \%$. The received data shows, that the structure of a seam should be ferritic (according the diagram Sheffler – ferrite with 10 % austenite). Structure of a fusion zone and a fracturegram of the destroyed surface of a seam are presented in Fig. 5. It can be seen, that the structure of a seam is more ferritic-martensitic, destruction of a seam is fragile and occurs in the fusion zone. Such seams can be used at static loading and under high temperature of operation of the construction.

Generalizing all the facts stated above, it is necessary to note, that the presence in a seam of layers strongly reduces their reliability. Therefore it is necessary to seak that the structure of a seam, whenever possible, would be uniform, and zone of thermal influence would be as small as possible.

4. CONCLUSIONS

1. At welding of the heat resistant nickel-chromium steels, seams with a high degree of austenitiness distinguish by high reliability and have viscous character of destruction.
2. At welding of the heat resistant chromium steels by austenitic or austenitic-ferritic electrodes, seams have complex austenitic-ferritic structure, and also martensitic inclusions in a fusion zone. The destruction of such seams more often occurs in a fusion zone and has a fragile character, therefore the reliability of them is much lower.
3. The structural transformations in metal occurring after hardening of a seam can cause formation of cracks in a seam and in a zone close to seam.

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