

# The use of Ni-Cr-Si-Be filler metals for brazing of stainless steels

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**Abstract.** Nanocrystalline ribbon filler metal-alloys of system Ni-Cr-Si-Be are produced by the rapidly quenching of the melt method. By these filler metals carried out high temperature vacuum brazing of austenitic steels (12Kh18N10T and Kh18N8G2) and austenitic-ferritic class EI-811 (12Kh21N5T). The basic laws of structure-phase state foundation of brazed joints are determined, features of the interaction of the molten filler metal to the brazed materials are identified, the optimal temperature and time parameters of the brazing process are determined.

## 1. Introduction

Nowadays, brazing alloys containing boron are widely used for connecting stainless steels. One of the major problems in the application of boron filler metals is formation of heterogeneities in the brazed seam and heat affected zone, [1] which can negatively effect on the performance characteristics of the brazed joints and even cause destruction, as they adversely affect its fatigue strength and corrosion resistance [2]. Reducing the mass percentage of boron in the composition of the filler metal does not completely solve the problem. Therefore, new brazing alloys that do not contain boron on the basis of Ni-Cr-Si-Be for brazing stainless steels austenitic and austenitic-ferritic class are developing now.

The requirements for strength properties and technology for preparing compounds of corrosion resistant steels are constantly increasing with the development of aerospace technology, the creation of advanced missile, space and aircraft design and manufacture of cellular or lattice panels and plate heat exchangers. Increasing the strength of connections can be achieved through the technological solutions or the use of new materials.

The brazing has received a significant development among the methods of creating a permanently connection, which widely used in mechanical engineering. The use of brazing allows provides the compounds that can withstand high temperatures, mechanical stress and the effect of the active media for a long time without significant deterioration of their properties [3]. Therefore, the actual problem is to improve the mechanical properties of brazed joints by optimizing of structures and the development of new filler metals, improving their properties and technological modes of brazing.

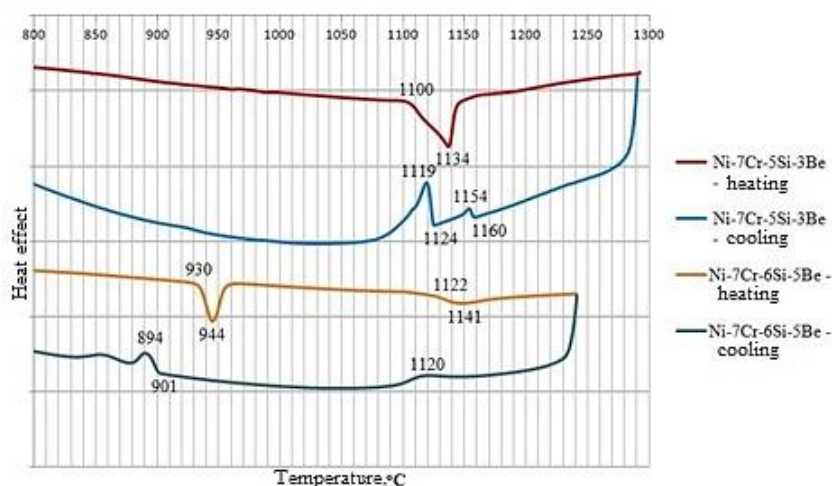
Nowadays rapidly quenched filler metals is widely apply. They are used in powder form or in the form of a ribbon with thickness of 20 ... 80  $\mu\text{m}$ . This is a special category of filler metals, which represent a new class of advanced materials [4]. Such alloys produced ultrarapid quenching technique that gives certain advantages in the process of melting and interaction of the melt with brazed materials. It improves the quality of brazing, reduces the amount of defects and the formation of intermetallics in the brazed joints [5].



The high strength of the brazed joint provides a diffusion brazing. Objective of the diffusion brazing, as an independent process for producing brazed joints, is to perform the crystallization process so as to provide the most equilibrium structure of compounds and thereby increase the temperature of desoldering of the seam, improve the strength, plasticity, electric conductivity, and to prevent the formation of low-strength and fragile cast structure of intermetallic compounds in the seams. The solidification of the joint occurs with this brazing during the isothermal holding and the structure of the seam is more homogeneous [6, 7].

## 2. Experiment and methods

The temperature characteristics and microstructure of brazing alloys of Ni-Si-Be and Ni-(Cr)-Si-Be were analyzed and two brazing alloys Ni-7Cr-5Si-3Be and Ni-6Si-5Be wt. % have been selected to study by its temperature and mechanical properties. Figure 1 shows the differential thermal analysis (DTA) for these alloys (graphs are shifted for clarity).



**Figure 1.** DTA of alloys Ni-7Cr-5Si-3Be and Ni-7Cr-6Si-5Be, wt. %.

The most perspective alloys in the system Ni-Cr-Si-B for brazing stainless steels are Ni-7Cr-5Si-3Be and Ni-7Cr-6Si-5Be. The joint brazed by filler metal Ni-7Cr-5Si-3Be has high strength and corrosion resistance due to chromium and relatively low melting point. As the alloy is ductile enough, a flexible tech ribbon was obtained from it. Alloy composition Ni-7Cr-6Si-5Be has a low melting point due to low melting eutectic (brazing temperature of such filler metal proceeding from the DTA may begin with 1070°C). However, this alloy has very high strength and low ductility, so the result the brittle ribbon was obtained by spinning. The filler metal was used for brazing in the form of pieces of ribbon.

Cylindrical (12Kh18N10T) and rectangular patterns (12Kh18N10T and EI-811 (12Kh21N5T, austenitic-ferritic)) were used for brazing. Cylindrical samples have a diameter of 10 mm and a height of 70 mm (GOST 28830-90). Rectangular samples have a long (wide) to (20 ... 30) mm and a height (3 ... 5) mm. The ribbon of filler metal was attached on the surface of sample by point capacitor welding. Filler metal thickness of 50 µm was used in a single layer and in the case of brazing the cylindrical samples it was placed directly into the brazing gap, and in the case of rectangular samples – near the brazing gap, so that the filler metal contact with a gap. Brazing of rectangular samples was carried out in clamps, and brazing of cylindrical samples was carried out in a special conductor.

The wedges were made specially to investigate the dependence of the joint overgrowing during the brazing process from the width of the gap. The gap between the rectangular steel plates was provided by tungsten wire thickness of 100 µm.

Structural studies of the brazed joints were carried out using metallographic microscope METAM PB-21-1 for the observation of the microstructure in the reflected and polarized light. It increases from x50 to x1000.

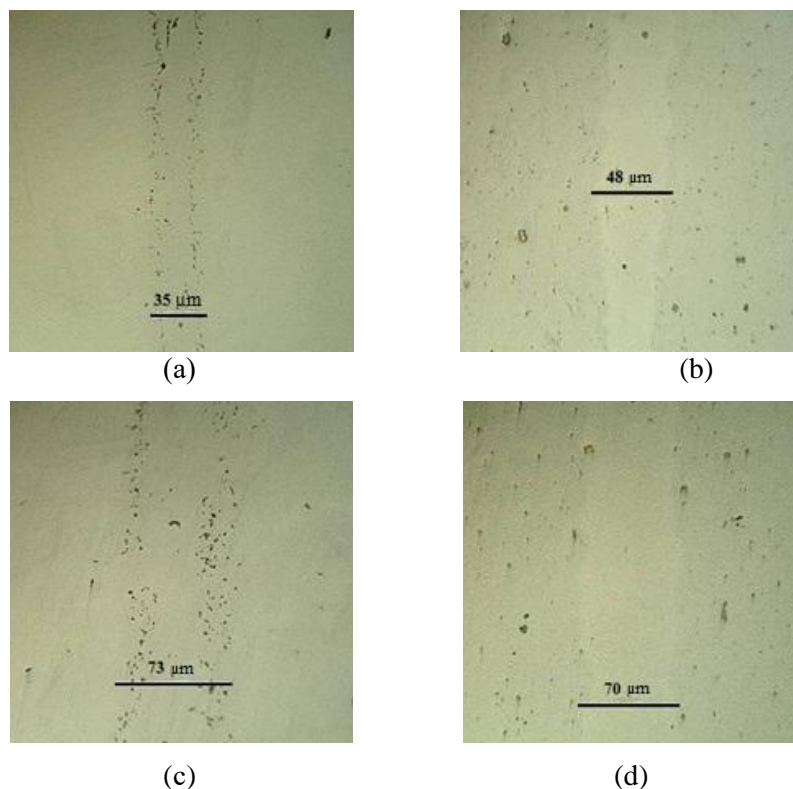
Determination the Vickers microhardness of brazed joint was carried out on the digital micro durometer Future-Tech FM-800, which has the rate of load 50 m / s, the load time of 20 seconds, the accuracy in accordance with GOST 9450.

Mechanical properties of brazed cylindrical samples at tensile were determined using two-column universal testing machine QUASAR 50, which has the maximum force is 50 kN.

### 3. Results and Discussion

It is necessary to determine the optimal mode of brazing to investigate the mechanical properties of the brazed joint, since the structure of the brazing joint, and therefore the mechanical properties, are depended strongly on the gap width and the holding time at brazing temperature.

The gap width corresponding to that time brazing, at which the fusible elements diffuse fully into the base material and a solid solution forms, was determined, because the eutectic has a low ductility and its presence in the joint is undesirably. Figure 2 shows the structure of the seam, which obtained after brazing of Kh18N8G2 (austenitic) and EI-811 steels by filler metal Ni-7Cr-5Si-3Be wt. %, with a different holding time.



**Figure 2.** Structure of the brazed joint and the magnitude of the gap, at which the overgrowing of joint is complete,  $T_{\text{brazing}} = 1150^{\circ}\text{C}$  (filler metal Ni-7Cr-5Si-3Be, wt.%), (a) – Kh18N8G2,  $t_{\text{brazing}} = 30\text{ мин}$ ; (b) – EI-811,  $t_{\text{brazing}} = 30\text{ мин}$ ; (c) – Kh18N8G2,  $t_{\text{brazing}} = 1\text{ час}$ ; (d) – EI-811,  $t_{\text{brazing}} = 1\text{ час}$

According to the structure of brazed joints it can be seen that overgrowing of joint occurs for the steel in the gap size of 30-50 μm during brazing at the holding time of 30 minutes and the holding time at 60 minutes - 70 μm. Therefore, heating to 1150 °C for 40 minutes at the gap size 45-50 μm

were selected for brazing cylindrical samples for mechanical testing. The black particles are observed in the structure of joint and heat affected zone for Kh18N8G2 steel. Apparently, this is related to a high content of impurities in this steel (the steel are used in the technical purity).

After the optimal modes of brazing were installed, the plates were brazed with this filler metal considering gap size, brazing temperature and holding time. The values of microhardness of brazed joints were obtained. The microhardness of brazing joint obtained by the filler metal Ni-3.5Fe-7.5Cr-4.5Si-2.6B (1301A) wt. % were measured to compare. The results are shown in Table 1 (error  $\pm 120$  MPa). Alloy STEMET 1301A is studied in detail in the paper [8].

**Table 1.** Microhardness of samples brazed with different modes, in MPa.

Sample	Steel	Joint		Brazing mode
		fillet	solid solution	
Ni-7Cr-5Si-3Be/Kh18N8G2	1900	2800	2200	1150 °C, 1 hour
Ni-7Cr-5Si-3Be/EI-811	2700	2600	2000	1150 °C, 1 hour
Ni-7Cr-5Si-3Be/X18H8Г2	1500	2700	2000	1150 °C, 30 min
Ni-7Cr-5Si-3Be/ EI-811	3100	2800	2200	1150 °C, 30 min
1301A/ Kh18N8G2	1600	8700	3000	1150 °C, 15 min

The best mechanical characteristics of brazed joint will be achieved if the steel and the joint with loads will behave as a single entity. Therefore, the hardness of them should not vary greatly. In the case of using filler metal containing beryllium microhardness of the steel and the joint (fillet as well) are equal within the measurement error. The microhardness value in fillet area is extremely high compared with the microhardness value in the joint, when using boron filler metals. As known, the strength of fillets contributes significantly to the strength of the brazed joints [9].

The cylindrical samples were brazed at 1150 °C and holding time of 40 minutes for tensile test. The specimens brazed three filler metals: Ni-7Cr-5Si-3Be, Ni-7Cr-6Si-5Be and Ni-3,5Fe-7,5Cr-4,5Si-2,6B (1301A) were tested.

During tensile test of samples brazed with filler metal Ni-7Cr-6Si-5Be the destruction was not along the seam, it occurred on steel; therefore, the connection can withstand loads greater than steel. This result says about the prospects of this filler metal.

The compounds, which brazed with filler metal Ni-7Cr-5Si-3Be, showed better mechanical properties than the compounds, which brazed with boron filler metal 1301A. Averaging the value of tensile strength, which can withstand the connection brazed with filler metal Ni-7Cr-5Si-3Be, the value obtained ( $530 \pm 50$ ) MPa, and for 1301A - ( $420 \pm 30$ ) MPa.

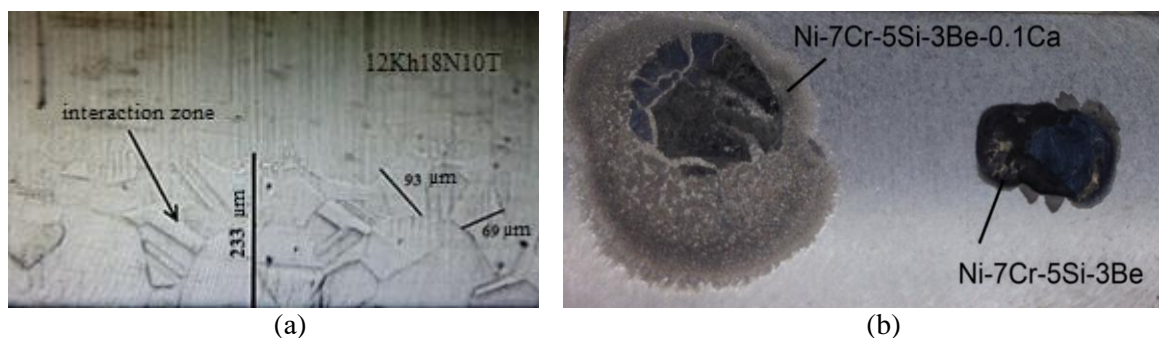
Analyzing the experimental data obtained as a result of tensile tests, it can be concluded that the connection Kh18N10T / Ni-5Si-7Cr-3Be / Kh18N10T shows better strength values than the connection brazing with boron filler metal (Ni-3,5Fe-7, 5Cr-4,5Si-2,6B), which speaks about the prospects of filler metals of Ni-Si-Cr-Be.

If we choose the optimal mode of brazing and clearance, in which the eutectic in the joint will disappear completely, it is possible to get stronger compounds in combination with a low temperature brazing.

The experiment on spreadability was carried out with the filler metal Ni-7Cr-6Si-5Be, wt.% on substrate of steel 12Kh18N10T at 1100°C for 1 hour. A good interaction with the steel was received (Figure 3a). The diffusion zone is 230  $\mu\text{m}$ . Therefore, this filler metal is more promising for brazing, because most of stainless steels is better brazing at temperatures not exceeding 1120°C as the loss of strength and grain growth are occurred above this temperature, which leads to embrittlement of the material.

Beryllium - an element that has a greater affinity with oxygen, and there is a possibility of formation of oxides, so additional studied of the effect of calcium, as a deoxidizer, on the spreadability

of filler metal Ni-5Si-7Cr-3Be was carried out. It was added 0.1 wt.% Ca. Figure 3b shows the results of an experiment on spreading filler metal with and without calcium on steel 12Kh18N10T at the temperature of 1150 °C and holding time 30 minutes. Calcium increases the spreading about three times.



**Figure 3.** A study of physico-chemical interaction of the filler metal with the substrate of steel 12Kh18N10T, (a) - filler metal Ni-7Cr-6Si-5Be, (b) - Ni-5Si-7Cr-3Be, wt.%.

#### 4. Conclusions

The wedge patterns for different modes to determine the optimal mode of brazing steels Kh18N8G2 and EI-811 were brazed. As a result the mode was selected: 40 minutes at the temperature of 1150 °C and at the gap size of 50 μm.

The brazing of cylindrical samples made of steel Kh18N10T by filler metals Ni-7Cr-5Si-3Be and Ni-7Cr-6Si-5Be was carried out under this mode. Tensile strength in uniaxial tension of these samples exceeded 500 MPa.

It is shown that the filler metal Ni-7Cr-6Si-5B interacts well with the steel at the temperature of 1100°C (diffusion zone is 230 μm). The modification by calcium of the original filler metal was carried out and the spreadability was increased is about three times.

#### Acknowledgements

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