THE LAYERED STRUCTURE OF COMPOSITE MATERIALS BASED ON NIOBIUM ALLOY OBTAINED BY THE SOLID-PHASE TECHNOLOGY

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Abstract

The methods of diffusion welding and pack rolling in two cycles experimental samples were made of composite materials, differing in functional properties: the superconducting multilayer tape based alloy Nb-50Ti, stabilized with copper and refractory material with a layered structure. From the X-ray spectral analysis concluded that interdiffusion between the layers in multilayer composites with the formation of expected alloys and chemical compounds occurred mainly due to the diffusion of niobium and carbon. Due to the high mobility of atomic carbon was able to penetrate all the structural components of the composite and to form the reinforcing phase in the form of carbide precipitates and layers of silicon-carbon chemical compound.

Keywords: *composite, solid-phase reaction, superconducting material, niobium-titanium alloy, heat-resistant material, diffusion welding, layered structure*

1. INTRODUCTION

Composite materials represent a complex system with two, three or more structural components, each of which performs certain functional role. Thus, in the heat-resistant composites with multilayer structures based on alloys of Nb–Al and Ti–Al [1], durable layers of intermetallic compounds of niobium or titanium with aluminum attached heat resistance of the composite system. Layers of plastic Nb- or Ti-solid solution, alternating with intermetallic layers, preventing the propagation of cracks that occurred in neighboring layers, made a composite crack resistance. This material in the form of plates with a total area of 10–15 cm^2 and a thickness of 1–3 *mm* was prepared by diffusion welding of multilayered Nb/Al- or Ti/Al- packages under pressure.

In the superconducting multilayer tape of nano-sized alternating layers of Nb and NbTi-alloy [2] layers of NbTi-alloy were carrying superconducting current, and Nb-layers were pinning centers superconducting vortices. If in the film still and the layers of copper were present, they were stabilized superconductivity of entire system. This tape of ~50 microns thick was obtained in two cycles. In the first cycle, the packets collected from Nb-foils and foils of NbTi-alloy and subjected to rolling. In the 2nd cycle were rolled package of Cu/(Nb/NbTi)/Cu, collected from multiple multilayer foils after the 1st cycle and the outer copper plates.

Veritable boom of superconducting niobium-titanium alloy research of occurred in the period 1960-1970's and ended development of industrial technology of multi-core superconducting materials based on them. Currently, research on them, from the viewpoint of superconductivity do not conducted.

In this paper, to obtain a superconducting ribbon cable, based on a deformable NbTi-alloy are invited to do without it at the initial stage producing, using in the1st cycle Nb/Ti-packets typed foils of pure metals. If there is interest in a more or less large-scale producing projects of superconducting tape material from NbTi, it is possible to abandon the NbTi-alloy melting – quite expensive and time consuming process.

In contrast to superconducting Nb-Ti alloy to heat resistant alloys of niobium, in many of which titanium is present as an alloying element is currently great interest. But work on composite materials with alloys, similar to our research, is just beginning. Consider some of them, are the closest to us by the method of preparation.

In [3-5] the initial multilayer billet was collected from Nb- and Al-foils. The layered structure of niobium and the intermetallic compound formed at the diffusion welding under pressure during a 4-step heat treatment of the work piece. A pressure from 15 to 30 *MPa* was applied at the last stage of heating. Composite structure depended on the ratio t_{Nb}/t_{Al}, where t_{Nb} and t_{Al} − thickness niobium and aluminum, respectively, and on final temperature of welding.

In composites with relationships t_{Nb}/t_{Al} = 4, 2.5 and 2 after welding at 850°C for 2 hours and at 900°C for 10 hours structure consisted of layers of a solid solution of aluminum in niobium Nb(Al) and intermetallic compound of $NbAl_3$. After 1200°C for 2 *h* in a work piece with t_{Nb}/t_{Al}, equal to 2, on the boundary between the Nb(Al) and $NbAl_3$ formation of Nb_2Al-compound was observed. Further increase in temperature in the last stage of heat treatment to 1200 and 1400°C led to the formation of a layered structure of Nb(Al), Nb_2Al and Nb_3Al. Finally, the structure of Nb(Al), $NbAl_3$, Nb_2Al and Nb_3Al formed into a composite with $t_{Nb}/t_{Al} \approx 1{,}4$ after 1500°C.

In [6] at the initial stage also used packages assembled from foils of pure niobium and aluminum with thicknesses of 200 and 50 microns respectively. They was subjected electro pulse discharge in a spark plasma sintering (SPS-method) at a pressure of 8 *MPa* for different modes. After heat treatment at regime 500°C/1.8 *kc* + 1400°C/0.9 *kc* able to obtain a structure consisting of only the compound Nb_3Al.

Earlier in studies on the superalloy material of the intermetallic compounds of niobium or titanium with aluminum for forming source packets, we also used a foil of pure niobium or titanium and aluminum. In this paper, in the preparation of packages are used alone, two or more foils of the deformable Nb- and Ti-alloys. It turned out that in this case it is possible to obtain multilayered structures with layers of the alloys are very different in composition from the initially estimated for foils.

2. METHODS PREPARATION AND STUDY OF MATERIAL STRUCTURE

2.1. Diffusion welding of packages and rolling

For producing of superconducting tapes based on Nb−Ti alloy and heat-resistant composite of niobium, titanium and molybdenum as the main components used diffusion welding of multilayer packages under pressure and their subsequent rolling at room temperature.

Diffusion welding of packets was carried in upgraded vacuum apparatus ADW-10 (Fig. 1) having cylindrical configuration the heater of high strength graphite capable providing the temperature of 1700°C. If in compiled packages Al-foil were present, the welding was carried out in two stages. In the first stage welding temperature not exceed the melting temperature of aluminum and maintained in the range 600–620°C, to prevent it leaking from the. Aluminum was associated in an intermetallic compounds $MeAl_3$, where Me = Nb or Ti, when welded packages of Nb/Al or Ti/Al. Welding of packets not containing a low melting elements made in one step.

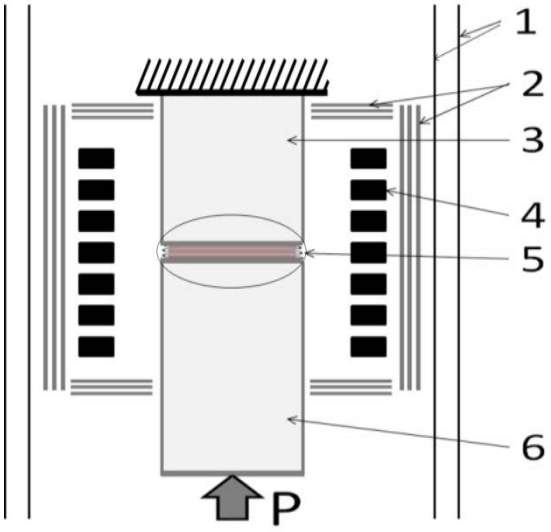

Fig. 1. The relative position of the main assembly units of an apparatus for diffusion welding: 1 – water cooled camera body, 2 – set of thermal shields of pressed graphite wadding and Mo-foil, 3 – stationary punch, 4– heater made of high strength graphite, 5 – test package, 6 – movable punch, P – effort

In other cases, diffusion welding took place at the same temperature. The heating rate was generally ~10 *deg./min*. The package was placed between the movable and stationary punches. Between the punches and package the graphite foils of brand Graphlex GF-G 0.3 *mm* thick were laid.

Deformation welded packages carried out at the room temperature on 4-roller mill of fine rolling. The degree of deformation per pass was 2–3%. After rolling, the tape was cut into pieces of the desired length. Of these segments was going to a new package of the required design and he was subjected to diffusion bonding for the second time.

For layered heat resistant material based on niobium alloy the technological process came to an end. In the case of superconducting composite package welded rolled at room temperature to a final tape thickness of 0.1 *mm*. In the case of superconducting composite the welded package was rolled at room temperature to a tape of final thickness equal 0.1 *mm*.

2.2. Investigation of materials structure

To study the structure of composites used scanning electron microscopy and X-ray spectral analysis (XSA).

Microstructural studies involving imaging of objects in the secondary and reflected (back-scattered) electron and X-ray diffraction, carried out on digital scanning electron microscope Tescan VEGA-II XMU and CamScan MV230 (VEGA TS 5130MM). Both microscopes have W-cathodes and equipped with YAG-detectors secondary and reflected electrons and X-ray energy dispersive microanalyzer.

Studies have been performed at an accelerating voltage of 20 *kV*. The size of the electron beam in the best case (on the surface of the reference sample Co) in one of the units was 240 *nm* at a current of electrons absorbed 400 *pA*. In the 2-nd unit – 150 *nm* at a current of 120 *pA*. The depth of field of characteristic X-rays reached 5-6 microns. On the horizontal section is consistent with a circle, and in volume – spherical zone diameters ~10 microns. Shooting with micrographs carried out mainly in the mode of reflected electrons with a real contrast.

The carbon content was determined by the method “on difference” allow for the presence of additional alloy microsection of the same or similar composition but containing no carbon. But even with tweaks

analysis undertaken to determine the carbon is considered semi-quantitative. However, even with taking into account undertaken tricks analysis by definition carbon is considered semi-quantitative.

3. THE MICROSTRUCTURE OF COMPOSITES

3.1. Multilayered superconductive tape of Nb-Ti alloy

The superconducting ribbon multilayer material of Nb-50% Ti alloy stabilized copper was obtained in two cycles each of which consisted of packet rolling and diffusion welding. In the first cycle pack contained 40 Nb-foil and 39 Ti-foil thicknesses of 50 and 45 microns respectively. The estimated thickness of the package in the 1-st cycle – 3.755 *mm*. The package was subjected to diffusion bonding at 1050°C for 10 minutes under a pressure of 16.3 *MPa* and then rolled at room temperature (Fig. 2,*a*) to a thickness of 0.2 *mm*. Rolling direction of package corresponded to the rolling direction of incorporated in the package foils of niobium and titanium. It is seen that the composite structure in the cross section is an alternation of light and dark bands. Bright layers – this Nb-solid solution (Nb), containing titanium in the amount of the order of several tenths of a percent. Dark layers – alloy of Nb–(20–30) *wt.%* Ti

Calculated thicknesses of niobium and titanium on the end of the 1-st cycle were equal, respectively, 2.7 and 2.4 microns. But in reality, on the image the thickness of layers of the two components was varied from a few microns to about 10–15 microns.

In the 2-nd cycle package was going to in a certain sequence of the six segments of the tape obtained after the 1-st cycle, three plates of copper with thickness of 0.15 *mm* and 4 Nb-foil with thickness of 20 microns. Diffusion welding of this package was held at 900°C and a pressure of 19 *MPa* for 1.5 hours. At the end the package was rolled at room temperature to 0.1 *mm* thick tape. The calculated thicknesses of the individual layers (Nb) and NbTi-alloy ~150 *nm*.

Fig. 2,*b* shows a cross section of the packet after the 2-nd cycle of diffusion bonding has not been subjected to rolling to a thin ribbon section. 70% of its volume deals with two bands with 2-phase layered structure NbTi + (Nb). The rest of the volume falls on the stabilizing the outer copper plates and one inner Cu-layer. Between them and the conductive layers of multilayer NbTi + (Nb) are thin layers of niobium. They are diffusion barriers, preventing the interaction between Cu and Ti.

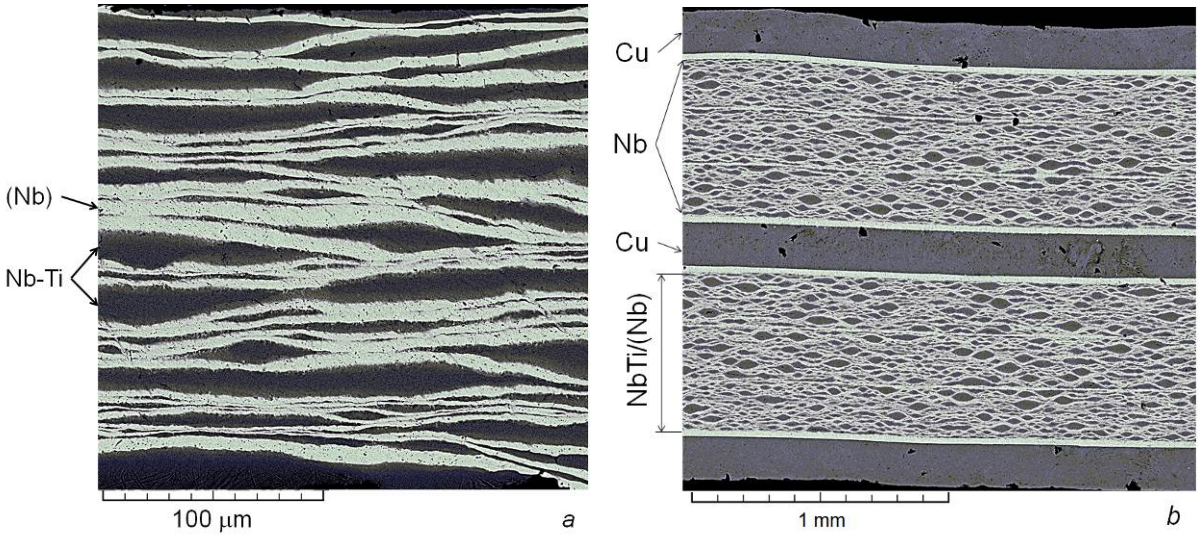

Fig. 2. The microstructure of the cross section of the band along the rolling direction after the 1-st cycle of diffusion bonding and rolling at room temperature (*a*) and the macrostructure of the packet after the 2-nd cycle of DW (*b*): (Nb) – Nb-solid solution

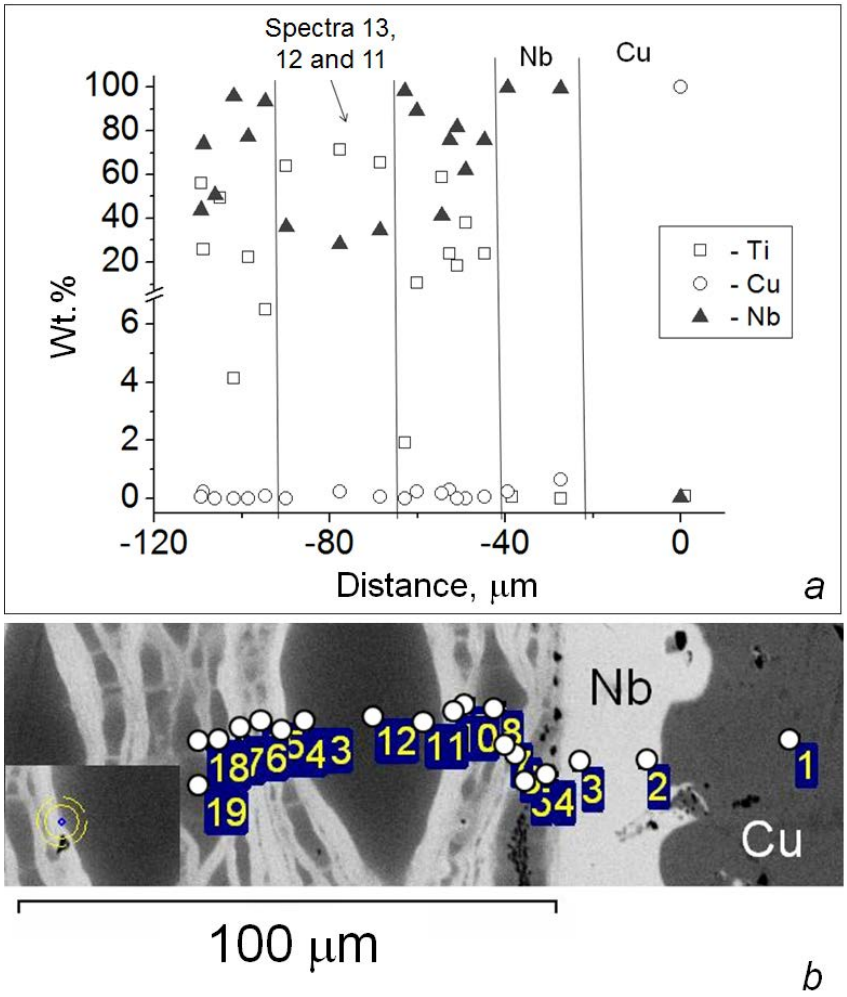

Fig. 3. Concentration profiles of Nb, Ti and Cu (*a*) and a fragment of the microstructure of the multilayer interlayer solid NbTi /(Nb) near the stabilizing copper layer (*b*): 1-19 – spectra rooms. Left below shows the area of influence of characteristic X-rays

3.2. XS-analysis results and discussion

The initial ratio of Nb- and Ti-foils was such that the composite NbTi/(Nb) remained two-phase and consisted of an alloy Nb-50 *wt.%* Ti and (Nb). Fig. 3 presents the results of scanning electron microscopy and XS-analysis accompanying her in the form of concentration profiles of niobium, titanium, and copper. The analysis was conducted on the boundary between the copper stabilization layer (spectrum 1) and the conductive layer NbTi/(Nb). Therefore at the microstructural fragment was also a barrier layer of Nb (spectra 2 and 3).

Concentration profiles of niobium and titanium showed that in the 2-phase layer of NbTi/(Nb) layers from pure titanium is completely absent. The highest content of titanium, ~65 *wt. %*, was in the " thickenings" of dark color (spectra 11, 12 and 13). They had the option reliably to determine the concentration of elements, without taking into account the excitation zone created by the characteristic X-rays. Other plots of NbTi-alloy layers are looked whiter by contrast. This is an indirect proof that they niobium contained more than in the spectra of 11-13. Indeed, in Fig. 3*a* there is enough spectra with ~50 *wt.%* Nb and ~50 *wt.%* Ti. In layers of the light contrast identified as Nb-solid solution, the concentration of titanium in the best case does not exceed 20 and often remained at the level of a few *wt.%*. In summary, we can say that the diffusion interaction between niobium and titanium occurs mainly due to the diffusion of niobium into titanium layers, but not in the reverse direction.

Based on the conducted XS-analysis can be said that the plan supplied experiment was achieved. Alloy Nb50Ti layers, having the highest second critical magnetic field capable of conducting large electric current in magnetic fields up to 7–8 Tesla. In superconducting materials just is used alloy Nb-Ti of this composition. An interlayers of Nb-solid solution with a titanium content of 5–10 *wt. %* are passed to its normal state in the low magnetic fields and become effective pinning centers of superconducting vortices. In multicore superconductors of niobium-titanium alloy pinning centers are fine particles of α-phase evolved in low-temperature (300–350°C) annealing ready-made cables. In composite superconducting materials of Cu/Nb/NbTi, in which pinning of vortices occurred at boundaries of NbTi-Nb, high critical current density is achieved without the low-temperature annealing [2].

3.3. Multilayer composite with reinforcing carbide phases

In the 1-st cycle packet was going to from thin foils of alloys of niobium Nb-2 *wt. %*Zr and Nb-0.1 *wt.%*C, molybdenum and titanium-based alloy. The sequence of layers and the design of the package can be written as

NbZr / [Σ] / NbC / NbZr / [Σ] / NbC / NbZr …/ [Σ] / NbC, (1)

wherein: [Σ] – [Ti-alloy/NbC /Mo/NbZr/Ti-alloy] (Ti-alloy: 10.0 %Cr–7.3 %Mo–2.6 *wt.%* Al, the rest or 80.1 *wt.%* – titanium). The number of components of the package: [Σ] – 5, NbZr – 5, NbC – 5 *pcs*. Package dimensions: 1.9×25×40 mm^3. Assuming that all of the layers by diffusion in the solid phase is uniformly mixed, it will turn an alloy of this composition: 66.23 % Nb–17.92 %Mo–13.06 %Ti–1.63 %Cr–0.68 %Zr–0.42 %Al–0.03 *wt.%* C.

The package was subjected to diffusion welding at 1350°C for 1 hour. The heating, holding and cooling takes place at a load of 1.5 *T*, which corresponds to a pressure of 14.7 *MPa*. The structure of package cross-sectional shown in Fig. 4.

Easy Ti-alloy was presented layers of dark color, heavy molybdenum – light layers. Other layers were determined by the above expression (1). After welding, the package was rolled at room temperature to a thickness of 0.2 *mm* and cut into segments of fixed length, which were used for assembly of packages in the 2-nd cycle.

One of the outer surfaces of band pieces was coated with a layer of Si-powder slurry in polyvinyl butyral. After drying of them was going to the package, ultimately representing a multilayered layers after the 1-st cycle, interspersed with layers of silicon powder. The regime of diffusion welding in the 2-nd cycle was practically identical to the first. The difference was in relatively slow heating (6.5–7 *deg./min*) on the interval from room temperature to ~600°C in order to glue had time evaporate.

The microstructure of package strikingly different from what it was after the 1-st welding (Fig. 5). First, significantly was broken the regularity of arrangement of layers as a result of rolling. Secondly, the difference of layers along the light contrast has decreased due to the diffusion interaction. But in spite of this in the direction perpendicular to the surface layers were well looked through "multilayer interlayers" "after the first cycle", separated by thin diffusion layers formed by the welding of the 2-nd cycle. Within each such interlayer can be distinguished to visually, at least three structural regions that differ from each other by light contrasts.

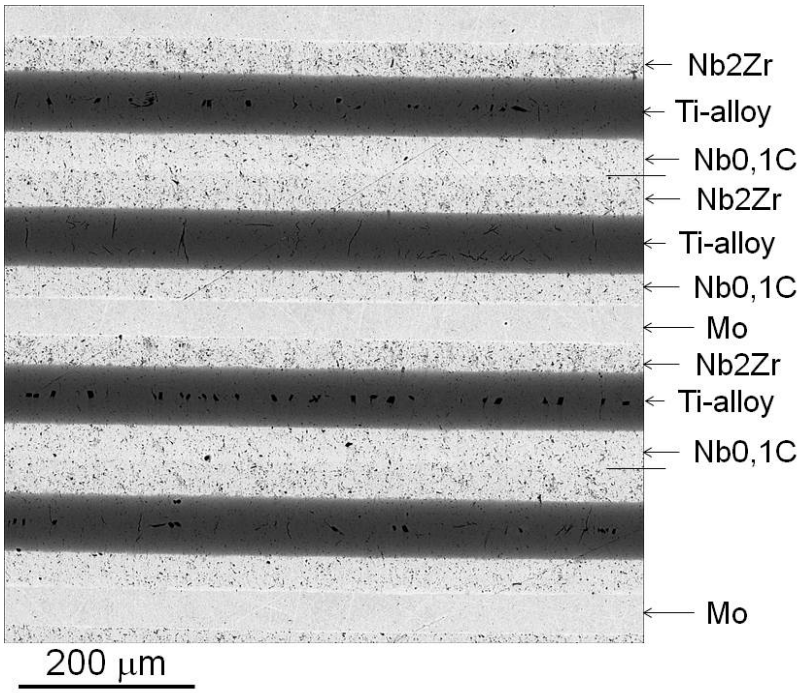

Fig. 4. The structure of the cross section of the package after the diffusion welding in 1-st cycle

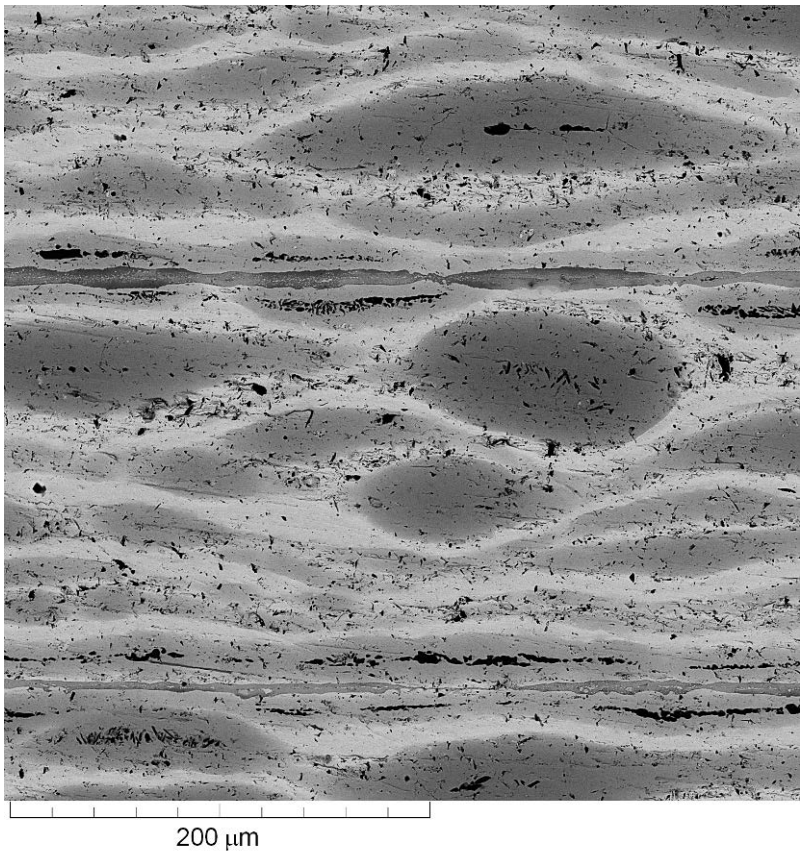

Fig. 5. The microstructure of the cross section of the package after diffusion bonding in the 2-cycle

Thin layers between the interlayers formed during process of the welding in place of silicon coatings, shown in enlarged scale in Fig. 6. Ibid clearly visible black fine particles are consolidated in the middle layers of Ti-alloy in the form of extended clusters. The composition of the identified structural objects will be defined below using a local XS-analysis.

3.4. Results of XS-analysis and discussion

To help to discuss the results of X-ray diffraction is presented in Fig. 7, and the results themselves are summarized in Table 1. According to the analysis in the microstructure of the composite were allocated such structural educations differ in the content of elements and light contrasts

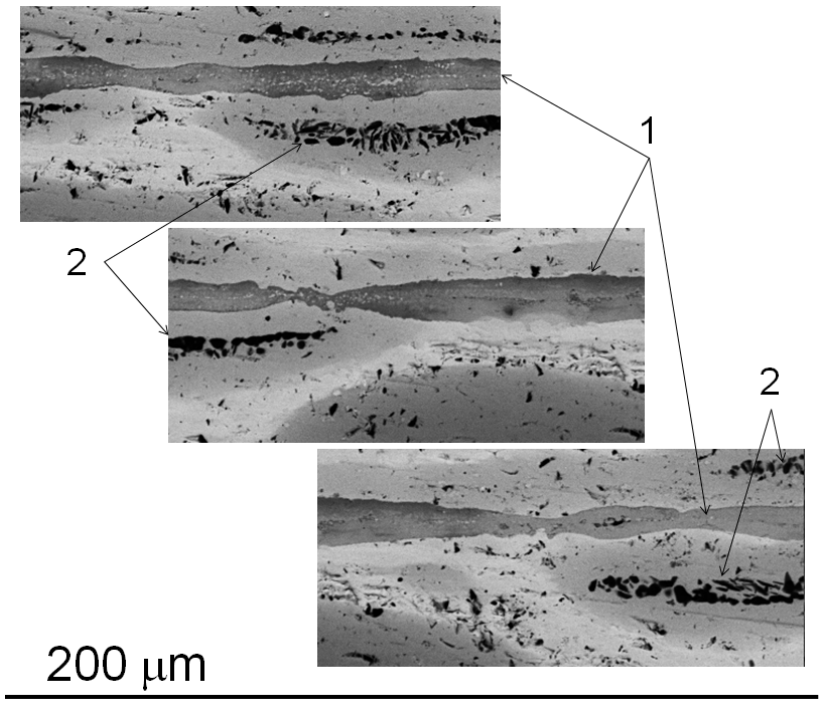

Fig. 6. The microstructure of a zone between "after the first cycle" layers: 1 – layers formed on Si-coating site; 2 – elongated accumulations of carbide precipitates

Table 1. XS-analysis of the phase structural components in the multilayer composite based on alloys of niobium, titanium, and molybdenum

Spectrumn umber	The concentration of elements						
	Al	Si	Ti	Cr	Nb	Mo	C
1. Structural plots of (Nb-Ti)-alloy, *wt.%*							
12 and 14	1,23 ± ± 0,08		35,80 ± ± 1,06	4,50 ± ± 0,32	51,24 ± ± 2,50	3,62 ± ± 3,36	3,56 ± ± 0,66
3, 4 and 15	0,75 ± ± 0,09		24,19 ± ± 2,95	3,10 ± ± 0,38	68,56 ± ± 4,39	1,62 ± ± 0,40	1,47 ± ± 1,03
2. Discontinuous layers of light-gray, *wt.%*							
6 and 11	0,57 ± ± 0,05	0,20 ± ± 0,14	12,54 ± ± 0,14	1,82 ± ± 0,33	76,54 ± ± 0,36	1,70 ± ± 0,10	6,63 ± ± 0,53
3. Layers of (Nb–Zr)- and (Nb–C)-alloys with the secretions of the second phase, *wt.%*							
2	0,18		1,24		95,62	0	2,57
4. Layers with a high content of molybdenum by *weight* (top) and *at.%* (lower line)							
5		0	0,55		0	96,58	2,62
		0	0,93		0	81,00	17,52
10			2,55		15,70	72,91	8,43
			3,15		9,97	44,85	41,41
5. The particles of niobium monocarbide by *weight* (top) and *at.%* (lower line)							
1		0,37			79,14	0	20,13
		0,52			33,41	0	65,73
6. The inclusion of titanium-niobium carbide by *weight* (top) and *at.%* (lower line)							
13	0,23		63,16	1,00	17,78	1,16	16,62
	0,28		44,94	0,65	6,52	0,41	47,16
7. The diffusion layer, instead of Si-coating between the "interlayers after the 1-st cycle" by *weight* (top) and *at.%* (lower line)							
7, 9 and 8	0,19 ± ± 0,18	14,90 ± ± 0,57	от 13,92 до 0,74	0,87 ± ± 0,37	71,91 ± ± 4,90		4,59 ± ± 0,74
	0,37 ± ± 0,34	28,43 ± ± 0,71	от 15,54 до 0,84	0,86 ± ± 0,36	41,54 ± ± 3,42		20,50 ± ± 3,35

Notes:

1. Unfilled table cells indicate that the concentration was below the error analysis of this element.
2. Zirconium is not represented in the table, because alloys with molybdenum and niobium it difficult determined due to the proximity of the characteristic spectral lines and its low concentration.

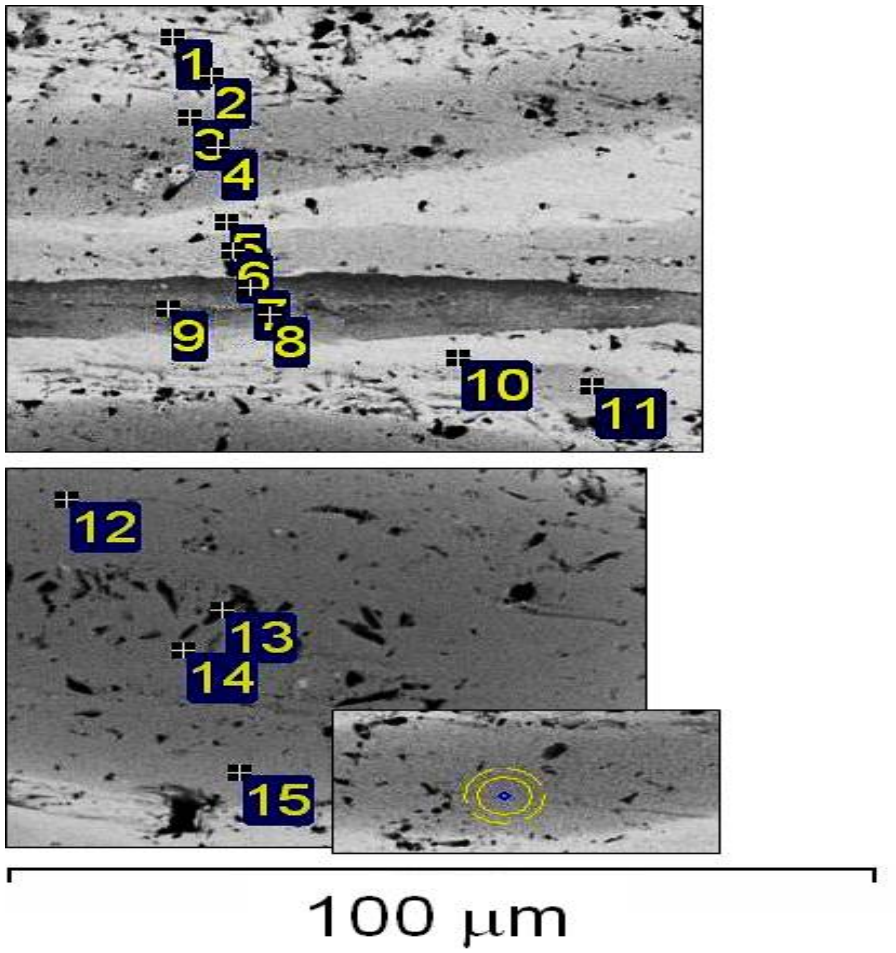

Fig. 7. XS-analysis results: 1–15 – numbers of spectra; inset at the bottom of the right – the zone of influence of the characteristic X-ray radiation

1. *Structural regions of gray color and oval shape with pointed ends of the major axis and discontinuous layers of gray color*. They were formed in place of the Ti-alloy layers [see. Table 1.1 and Fig. 7 (the spectra 12 and 14)]. After the 2-nd cycle in which niobium was became the main component. Also, if in the initial state Ti-alloy does not contain carbon, at the end of the 2-nd cycle in them was from 1.5 to 3.5 *wt. %*C. To the same type of structural component relate discontinuous layers of gray color ~10 microns thick (Fig. 7, spectra 3 and 4). By elemental composition they are identical to the first, but differ in concentrations of Nb and C: 68.56 ± 4.39 and 1.47 ± 1.03 *wt. %*, respectively. Niobium and carbon concentration in the middle of the oval region were respectively 51.24 ± 2.50 *wt. %*Nb and 3.56 ± 0.66 *wt. %*C (spectra 12 and 14), and at its periphery (spectrum 15) were comparable with the data for discontinuous layers.

2. *Discontinuous layers of light-gray* [see. Table 1.2 and Fig. 7 (the spectra of 6 and 11)]. They contain large amounts of carbon, equal to 6.63 ± 0.53 *wt. %* or 30 to 34 *at. %*. According to the state diagram of Nb–C, and niobium is contained in the layer in an amount of 75.54 ± 0.36 *wt. %*, this corresponds carbide of Me_2C, where Me – Nb, Ti (12.54 ± 0.14), Cr (1. 82 ± 0.33) and Mo (1.70 ± 0.10 *wt. %).*

3. *Light layers with secretions of the second phase* [see. см. Table 1.3 and Fig. 7 (spectrum 2)]. These are the remains of the single- and paired layers of niobium alloys Nb-2Zr and Nb-0,1C. They are ~95.6 *wt. %* consist of niobium. Besides it they contain a carbon in an amount up to 2.6 *wt. %* and titanium at level 1 *wt. %*. Zirconium in the family with niobium and molybdenum due to the proximity

characteristic spectral lines is difficult determined element, especially because its content is not enough.

4. *Layers with a high content of molybdenum* – from 96.5 to 73 *wt. %* [see. Table 1.4 and Fig. 7 (the spectra of 5 or 10)]. Among other metals in these layers are contained niobium – from 0 to 15.7 *wt. %* and titanium – from ~0.5 to ~2.5 *wt. %*. The concentration of carbon in the Mo-layers varies from ~2.6 to ~8.4 *wt. %*. If the lower limit of the concentration range according to the state diagram of Mo–C is closer to the solid solution carbon in Mo, the upper corresponds carbide phase based on molybdenum. Therefore we can not to deny the formation of this phase.

5. *Monocarbide inclusions of* NbC_{1-x} [see. Table 1.5 and Fig. 7 (spectrum 1)] are within the "light layers with the secretions of the second phase" and contain 33.4 *at. %* Nb and 65.7 *at. %* C. In these inclusions besides niobium and carbon Si was dissolved about 0.5 *at. %*. На это стоило обратить внимание, так как в самом слое его содержание было в 5 раз меньше, что ниже погрешности анализа по кремнию. This fact should be noted since in the layer itself content of Si was 5 times smaller. This is lower than the error of analysis for the silicon.

6. *Inclusions of titanium-niobium carbide MeC,* where Me – Ti and Nb, are either in the middle of structural formations of oval shape as separate secretions (see. Fig. 7, spectrum 13), or in the middle part of the structural formations with the same composition in the form of extended clusters of dark colored particles (refer to. Fig. 6.2). These structural formations were located near the interface of the two layers "after the 1-st cycle". The composition of titanium-niobium carbide: ~45 Ti, ~6.5 Nb, and ~47 *at. %* C. In it dissolved small amounts of Cr, Mo, and Al.

7. *The diffusion layer in Si-coating place between interlayers of "after the 1st cycle"* [see. Table 1.7 and Fig. 7 (the spectra of 7, 9, and 8)]. The composition of the formed layer: 41.5 Nb–15.5 Ti–28.4 Si–20.5 *at. %* C. This corresponds to a chemical compound MeX, where Me – Nb and Ti, X – Si and C. In a layer in addition to these elements chromium and aluminum are present in amounts ~0.9 and ~0.4 *at. %*, respectively.

After analyzing of the XSA results can draw the first conclusions. The fact that after the 2-nd cycle of the multilayer composite structure has changed significantly in comparison with that observed in the resulting diffusion welding after the 1-st cycle demonstrates the usefulness of the package rolling. A positive value of it is explained as follows.

In the process of rolling inside the layered composite which is stretched in a length of several times are released atomically clean, so called juvenile surface of contiguous dissimilar metals and alloys [7]. During the rolling these surfaces are approach each other at a distance of action of interatomic forces, and a result of the formation of metal contacts their clutch is happened. During plastic deformation it is called “grasping”. The ability of metals to “grasping” is the physical property of juvenile surfaces. In ideal conditions “grasping” is thermodynamically favored and should occur spontaneously, as the energy of a system of interconnected metal becomes smaller due to liquidation of free surfaces. Under ideal conditions understood the convergence of surfaces free from oxide and adsorbed films at a distance equal to the sum of atomic radii of the bonding surfaces. Rolling and is one way to obtain juvenile surfaces.

In this case, the formation of juvenile surfaces useful by the fact that through them more freely pursue the mutual diffusion of dissimilar atoms compared with those if the rolling not undertaken.

By results of XS-analysis, as in the case of multilayer composite Nb/Ti, it can be concluded that the titanium substantially does not participate in the mutual diffusion between the layers. Passive role in the diffusion is manifested and molybdenum. This is evidenced by the presence of structural components, niobium-rich, and also that in Mo-layers contain up to 15.7 *wt. %* niobium. And this despite the fact that in still the remaining parts of the structure, which were previously layers of niobium alloys with zirconium and carbon, niobium was contained up to 96 *wt.%*. This is the first thing.

Secondly, the carbon contained in foils of a niobium alloy, due to its atomic mobility managed to penetrate into all structural components. With his participation formed reinforcing phases in the form of precipitates of the titanium-niobium carbide and layers of the silicon-carbon compounds MeX, where Me = Nb and Ti, X = Si and C. The inclusions of NbC_{1-x} monocarbide, presented in initial foils of Nb–C alloy, were preserved until the end of the technological process, having undergone only a slight elongation during rolling. Moreover not exclude the possibility of a formation of carbide Me_2C, where Me = Nb, Ti, Cr and Mo (spectra 6 and 11) and carbide phase with molybdenum (spectrum 10).

In the resulting composite the heat resistance of material will provide carbide phases of niobium, titanium and molybdenum in the form of precipitates and layered formations and layers of silicon-carbon compounds with niobium and titanium formed instead of Si-coating. For crack resistance will respond layers of niobium alloy with Ti, Cr, and Mo (spectrum 2, 3, 4, 12, 14 and 15).

4. CONCLUSIONS

1. By means of the diffusion welding and the rolling of multilayer packages collected from foils of niobium, titanium and copper in two cycles were produced the experienced samples of the multilayered superconducting tape on the basis of alloy Nb–50Ti, stabilized copper and containing the thin barrier layers of niobium.

2. By similar technology was obtained the composite heat-resistant material with a layered structure which is constructed so that the carbide and silicon-carbon phases in the form of precipitates and the layers will ensure the heat resistance of the material, and layers of niobium-based alloy with Ti, Cr and Mo – crack resistance under normal conditions.

3. From XS-analysis, we can conclude that in the composites of Cu/(Nb/Ti)/Cu the formation of alloy Nb-50 *wt.%* Ti was occurred due to the diffusion of niobium atoms in the layers of titanium. Titan did not participate in that process. A similar behavior it was showed in the multilayer composite made up of foils of niobium, titanium and molybdenum alloys. The stirring of elements in this composite designed to be heat-resistant material was due to the diffusion of niobium and carbon. Due to its high atomic mobility of carbon was able to penetrate into all structural components of the composite. With his participation were formed the reinforcing phase in the form precipitates of the titanium-niobium carbide and layers of the silicon-carbon compounds with niobium.

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