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Kinetics of diffusion interaction in the Ti-NiCr system layered composites

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Abstract. The results of investigation of the diffusion interaction kinetics at the boundary of explosion welded Ti-NiCr system compositions during heat treatment are presented. The structure, chemical and phase composition of the formed diffusion zones are also studied. It is shown that the layered diffusion zone is formed at a temperature below the eutectoid transformation. Diffusion zone consists of solid solutions based on Ti2Ni, TiNi, and TiNi3 intermetallic compounds, as well as chromium-based solid solution inclusions along the boundary with the NiCr alloy. An increase in temperature above the eutectoid transformation leads to an intensification of the growth of the diffusion zone and the diffusion of nickel into the titanium alloy with the formation of a eutectoid structure in it. The use of alloyed titanium alloys instead of commercially pure titanium does not affect the phase composition of the formed diffusion zones, but slows down the diffusion processes.

1 Introduction

An increase in heat and wear resistance of titanium alloys is possible by creating functionally graded intermetallic coatings on their surface based on doped nickel and chromium aluminides [1-5]. For the formation of such coatings at the Department of Materials Science and Composite Materials of the Volgograd state technical university, a technology was proposed that provides for the deposition of a barrier layer of nichrome (Cr20Ni80 alloy) on the surface of titanium (titanium alloy) at the first stage by explosion welding, and at the second stage, aluminizing of the resulting workpiece by immersion in aluminum melt [6]. In this case, it is important to understand the features of the diffusion interaction of titanium alloys and nichrome at elevated temperatures under the conditions of heat treatment of coatings and operational heating. Many works are devoted to the study of the interaction kinetics of titanium with nickel at different temperatures and the resulting diffusion zones [7-9]. There are works devoted to the formation of Ti-NiCr composites [10-12], however, the issue of diffusion interaction in these compositions is practically not studied.

The aim of this work was to study the features of diffusion interaction at the joint boundary of explosion-welded layered composites of the Ti-NiCr system under high-temperature treatment.

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2 Eexperimental

2.1 Materials

The studies were carried out on composites Cr20Ni80 + VT1-0, Cr20Ni80 + OT4, and Cr20Ni80 + VT20 obtained by explosion welding. The chemical composition of titanium alloys and Cr20Ni80 nichrome alloy are shown in tables 1-2.

Table 1. Chemical composition of titanium alloys (wt%)

	Ti	Al	V	Mo	Zr	Mn	Si	Fe
VT1-0	98.6 – 99.7	-	-	-	-	-	< 0.1	< 0.18
OT4	91.6 – 95.7	3.5 - 5	-	-	< 0.3	0.8 - 2	< 0.15	< 0.3
VT20	84.9 – 91.7	5.5 - 7	0.8-2.5	0.5 - 2	1.5 – 2.5	-	< 0.15	< 0.3

Table 2. Chemical composition of Cr20Ni80 alloy (wt%)

Al	C	Cr	Fe	Mn	Ni	P	S	Si	Ti	Zr
≤0.20	≤0.06	20.0-23.0	≤1.0	≤0.6	base	≤0.02	≤0.015	1.0-1.5	≤0.2	0.2-0.5

2.2 Methods

Heat treatment of samples 10x10 mm in size was carried out in a SNOL 8.2/1100 furnace in an air atmosphere at temperatures from 700 to 850 °C. The lower limit of the regimes corresponds to the temperature not exceeding the eutectoid transformation temperature in the Ti-Ni system, and the upper limit corresponds to the temperature not exceeding the phase transition temperature of pure titanium. The exposure time of the samples was changed from 1 to 100 h.

Electron-optical studies and determination of the chemical composition (EDS analysis) were carried out on a scanning electron microscope Versa 3D Dual Beam. X-ray phase analysis (XRD) was performed on the Bruker D8 ADVANCE ECO diffractometer in radiation from a copper anode.

3 Results and discussion

Based on the results of the tests, graphical dependences of the thickness of the formed diffusion zone (DZ) on the temperature and time of testing were plotted (Fig. 1). At a temperature below the eutectoid transformation, the kinetics of DZ growth for a composition with commercially pure titanium (Cr20Ni80 + VT1-0) is maximum (Fig. 1 a). In the composition with alloyed titanium Cr20N80 + OT4, the growth rate of DZ is approximately 10% lower, and in Cr20Ni80 + VT20 it is more than 2 times lower than in Cr20Ni80 + VT1-0.

At a temperature above the eutectoid transformation (850 °C) (Fig. 1 b), a significant intensification of diffusion processes is observed. At the same time, the composition Cr20Ni80 + OT4 showed the maximum rate of DZ growth, and the minimum one, Cr20Ni80 + VT20.

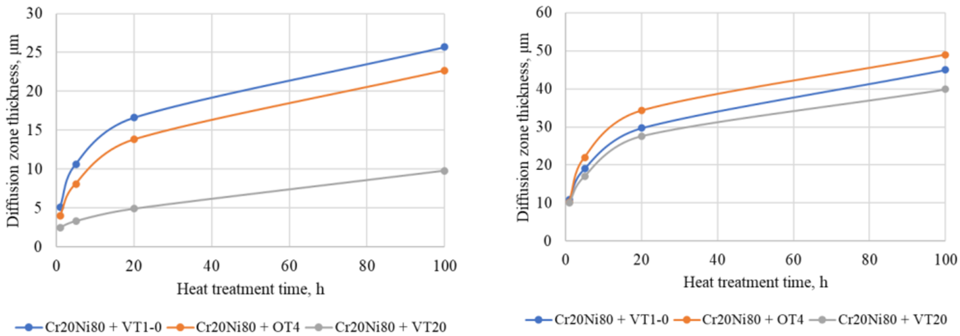
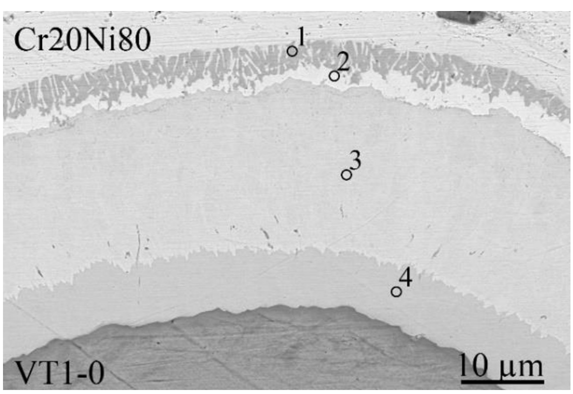


Fig. 1. Kinetics of diffusion interaction at 700 °C (a) and 850 °C (b)

Metallographic studies have shown that in the Cr20Ni80 + VT1-0 composite at 700 °C, a layered DZ is formed at the joint boundary, consisting of four clearly distinguishable regions (Fig 2). Point energy-dispersive analysis made it possible to establish that a continuous layer of Ti_2Ni intermetallic is formed on the side of the titanium layer, after which there is an interlayer of TiNi intermetallic, which makes up most of the DZ. On the nichrome side, there are two regions, one of which is inclusions of a solid solution of titanium in chromium, separated by thin layers of $TiNi_3$ intermetallic, and the second corresponds to a layer of $TiNi_3$ intermetallic of variable thickness. The distribution of chemical elements in the cross section showed the absence of diffusion of elements in nichrome and titanium.



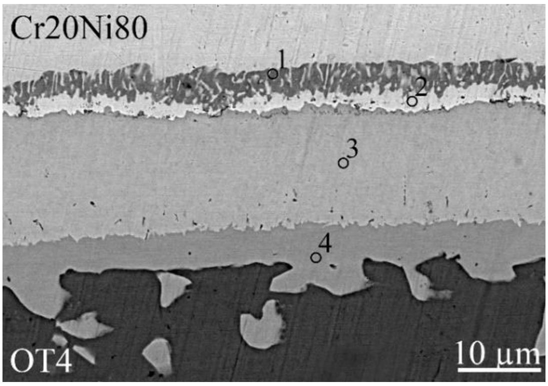
a

At. %	Ti	Ni	Cr
1	1.7	-	98.3
2	33.1	66.9	-
3	61.1	38.9	-
4	76.9	23.1	-

b

Fig. 2. Structure of the DZ in the Cr20Ni80 + VT1-0 composite after heat treatment 700 °C, 100 h (a) and the results of the EDS analysis (b)

In the case of the Cr20Ni80 + OT4 composite, at 700 °C, a similar DZ is formed, in which, instead of binary intermetallic compounds of the Ti-Ni system, solid solutions based on them are formed (Fig 3). The formation of solid solutions based on TiNi and Ti_2Ni occurred due to the diffusion of alloying components from the OT4 alloy, that is, Al and Mn. The fundamental difference in DZ compared to the Cr20Ni80 + VT1-0 composite is the formation of Ti_2Ni intermetallic inclusions in the titanium layer. The absence of light inclusions in the titanium structure at a distance of about 50 μm from the DM was also noted, which is due to a decrease in the Mn concentration in this region.

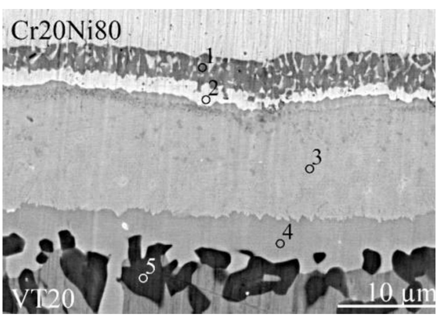


At. %	Ti	Ni	Cr	Al	Mn
1	3.3	13.7	83.0	-	-
2	24.1	75.0	0.9	-	-
3	48.0	49.7	-	1.5	0.7
4	66.0	31.3	-	1.0	1.6

a b

Fig. 3. Structure of the DZ in the Cr20Ni80 + OT4 composite after heat treatment 700 °C, 100 h (a) and the results of the EDS analysis (b)

In the Cr20Ni80 + VT20 composite after 700 °C, no fundamental differences in the DZ structure were noted (Fig. 4). On the basis of TiNi and Ti_2Ni intermetallics, solid solutions containing Al, Mo, V, Zr were formed. Along the boundary with the DZ in titanium, regions with an increased content of Al, reaching 16 at. %.



at. %	Ti	Ni	Cr	Al	Mo	Zr	V
1	3.3	10.1	85.9	0.5	0.1	0.2	-
2	23.3	74.0	1.7	-	0.2	0.4	0.4
3	45.7	49.6	-	3.4	0.2	0.5	0.7
4	58.1	37.7	-	3.6	0.3	1.0	-
5	81.2	-	-	16.5	0.6	0.8	1.0

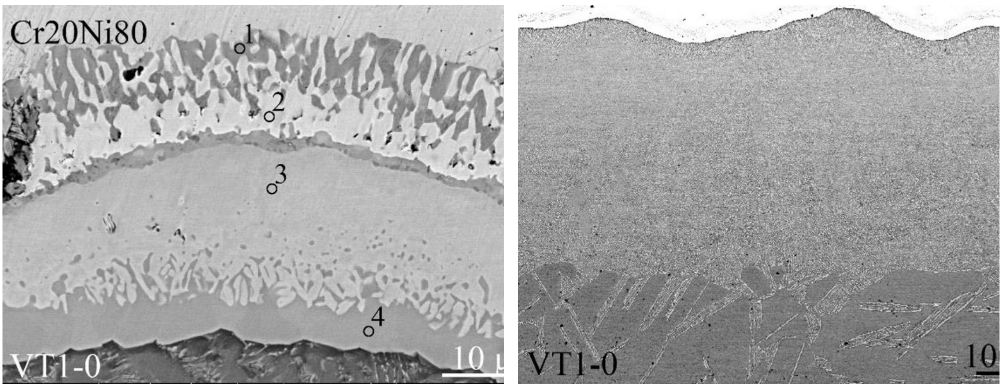
a b

Fig. 4. Structure of the DZ in the Cr20Ni80 + VT20 composite after heat treatment 700 °C, 100 h (a) and the results of the EDS analysis (b)

Conducting heat treatment at a temperature above the eutectoid transformation led to qualitative changes in the structure of DZ and titanium. The study of the DZ microstructure in the Cr20Ni80 + VT1-0 composite (Fig. 5) showed that after heat treatment at 850 °C, there is a significant intensification of diffusion processes and a change in the ratio of the thicknesses of the constituent layers in comparison with heat treatment at 700 °C. The proportion of the interlayer from the side of nichrome in the composition of the DZ increased significantly, along with this, the proportion of the $TiNi_3$ intermetallic compound in its composition also increased. A transition region appeared along the boundary between TiNi and Ti_2Ni intermetallics, corresponding to a mixture of these phases. The chemical composition of the phases in the composition of the DZ remained unchanged.

Heat treatment at 850°C led to active diffusion of nickel into titanium, whose solubility in βTi can reach 10 at. %, and the formation of a eutectoid mixture (Ti+Ti_2Ni) after cooling. The length of the region with a gradually decreasing nickel content exceeds 500 μm after 100 h of exposure. The resulting structure of the titanium layer is shown in Fig. 5 b.

The structure of the DZ in the Cr20Ni80 + OT4 composite (Fig. 6) is similar to the Cr20Ni80 + VT1-0 composite, but differs, as after 700 °C, in the formation of solid solutions based on TiNi and Ti_2Ni intermetallics. The diffusion of nickel into titanium OT4 led to the formation of a eutectoid structure to a depth of almost 400 μm after 100 h of exposure. The maximum content of nickel at the boundary of the DZ was 5 at. %. Due to the fine dispersion, a more uniform distribution of Al and Mn occurred in this area.



a b

At. %	Ti	Ni	Cr
1	5.4	2.8	91.7
2	22.8	72.9	4.3
3	48.9	49.2	1.9
4	67.3	32.1	0.7

c

Fig. 5. Structure of the DZ in the Cr20Ni80 + VT1-0 composite after heat treatment 850 °C, 100 h (a, b) and the results of the EDS analysis (c)

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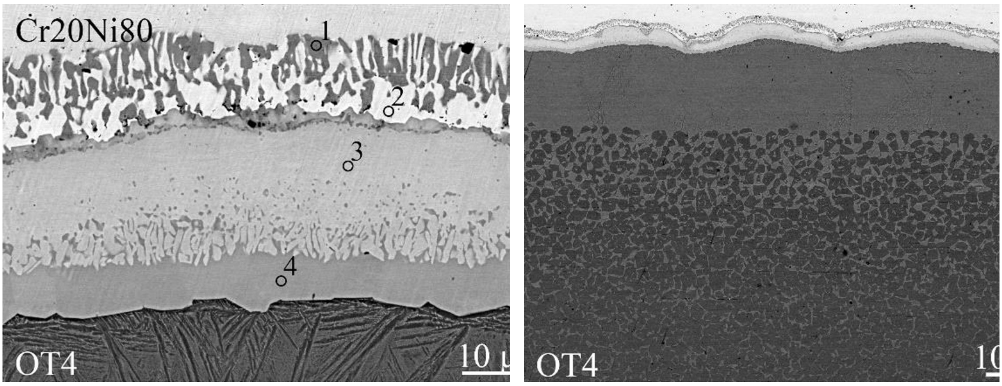


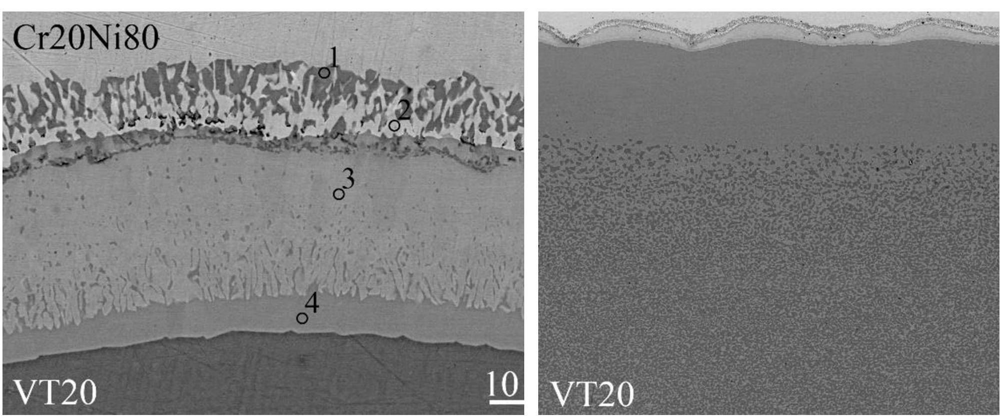
a b

At. %	Ti	Ni	Cr	Al	Mn
1	-	-	100	-	-
2	22.9	74.7	2.4	-	-
3	48.1	50.2	1.2	0.5	-
4	64.5	32.3	-	0.8	2.3

c

Fig. 6. Structure of the DZ in the Cr20Ni80 + OT4 composite after heat treatment 850 °C, 100 h (a, b) and the results of the EDS analysis (c)

In the Cr20Ni80 + VT20 composition after heat treatment at 850 °C (Fig. 7), no fundamental differences in the DZ structure were noted. Diffusion of nickel into titanium VT20 slows down significantly in comparison with alloys VT1-0 and OT4. The maximum content of nickel at the boundary of the DZ does not exceed 4 at. %, and the depth to which nickel diffused does not exceed 300 μm after 100 h of exposure.



a b

at. %	Ti	Ni	Cr	Al	Mo	Zr	V
1	1.2	2.6	96.2	-	-	-	-
2	22.2	73.5	3.7	0.7	-	-	-
3	45.0	50.5	1.2	2.5	0.2	0.6	0.1
4	62.4	32.7	-	2.7	0.2	0.9	1.1

c

Fig. 7. Structure of the DZ in the Cr20Ni80 + VT20 composite after heat treatment 850 °C, 100 h (a, b) and the results of the EDS analysis (c)

4 Conclusion

The replacement of commercially pure titanium by titanium alloys in explosion welded compositions of the Ti-NiCr system has practically no effect on the structure and phase composition of the diffusion zone formed at the joint boundary, but slows down the diffusion processes.

During heat treatment below the eutectoid transformation temperature, diffusion processes are localized at the joint boundary and lead to the formation of a layered diffusion zone consisting of solid solutions based on Ti_2Ni, TiNi, and $TiNi_3$ intermetallics, as well as chromium-based solid solution inclusions along the boundary with the NiCr alloy.

An increase in the heat treatment temperature above the eutectoid transformation significantly intensifies the growth of the diffusion zone, and also leads to the diffusion of nickel into the titanium alloy and to the formation of a eutectoid structure in it, the length of which is almost 10 times greater than the thickness of the diffusion zone.

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