VACUUM DIFFUSION WELDING OF γ-TiAl INTERMETALLIC ALLOY TO 12Kh18N10T STEEL

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A two-stage technology for vacuum diffusion welding of intermetallic alloy γ--TiAl to 12Kh18N10T steel using interlayers has been developed. It is shown that application of a nanolayered interlayer of Ti–Al system from the side of intermetallic and nickel interlayer from the side of steel provides a uniform distribution of microhardness in the bond.

Keywords: *vacuum diffusion welding, γ-TiAl intermetallic alloy, 12Kh18N10T steel, nanolayered insert, joint zone, microstructure, microhardness*

Complexity of welding intermetallics of Ti–Al system to steel is determined by low mutual solubility of titanium and iron, whereas formation of carbides, intermetallics and eutectics in the joint zone makes it impossible to perform direct welding of intermetallics to steel by any of the known fusion welding processes.

As a rule, joints of titanium and its alloys to steel, made by diffusion welding, have low impact toughness values [1–3].

In solid-phase welding of titanium to steel, interlayers, in particular niobium (or vanadium) and copper, are used to produce sound joints without formation of brittle intermetallic phases in the butt [4, 5]. These materials, however, differ from each other both by melting temperature and by strength characteristics (Table 1). Copper is used as material blocking carbon diffusion into niobium (strong carbide-forming metal). Main disadvantage of copper in this composition is its low melting temperature T_{melt} = 1083 °C.

According to the data of work [2], in welding of titanium alloys to stainless steel through intermediate barrier interlayers the copper region, through which fracture propagates, has the lowest strength in the joint zone.

There are few studies on welding intermetallics of Ti–Al system to steel [6, 7]. In diffusion welding of intermetallic of Ti–Al system (at.%: Ti–48Al–2Cr–2Nb) to steel without application of interlayers (temperature T_w = 950 °C, pressure P_w = 25 MPa, welding time t_w = 6 min) transition Ti_3Al + FeAl + $FeAl_2$/TiC intermetallic layers form in the butt between γ-TiAl and steel, leading to welded joint embrittlement [6].

Welding of intermetallic to stainless steel with application of thin interlayers in the form of titanium, vanadium and copper foils, preventing formation of brittle intermetallics in the butt, was studied in work [7]. Intermetallic alloy (at.%: Ti–47.2Al–1.17Ni–0.56Cr–0.11Nb) was welded to steel. Welding was performed at T_w = 1000 °C, P_w = 20 MPa, t_w = 60 min. At selection of welding temperature, the authors proceeded primarily from physical properties of copper, as at increase of welding temperature above 1083 °C melting of copper interlayer and copper pressing out of the butt take place, and welded joint strength decreases markedly [6]. At optimum welding mode, samples fail mainly through Ti_3Al–TiAl layer and partially through base metal (γ-TiAl).

The objective of our investigations was to develop a technology of vacuum diffusion welding (VDW) of γ-TiAl intermetallic alloy to 12Kh18N10T steel with a more uniform distribution of strength in the butt. The object of investigations were γ-TiAl intermetallic alloy (at.%: Ti–48Al–2Nb–2Cr) and 12Kh18N10T steel.

At temperature of γ-TiAl welding equal to 1000 °C, formation of physical contact in the butt is incomplete, because of high hardness and low ductility of the

Table 1. Mechanical properties of applied materials

Material	T_{melt}, °C	δ, %	σ_t, MPa	*E*, MPa
12Kh18N10T	1455	40	510–860	198,000
Copper	1083	60	216–235	128,700
Nickel	1453	35–40	390–490	201,900
Niobium	2468	30–40	345–491	89,100
Titanium	1668	40–55	245–345	108,000
γ-TiAl	~ 1450	1.5	550–900	180,000

Table 2. Composition and thickness of interlayers applied in welding

Interlayer type	Interlayer composition	Thickness, μm
Ti–Al	Ti–52 at.% Al	20
Titanium	Titanium	100
Niobium	Niobium	50
Copper	Copper	50
Nickel	Nickel	50

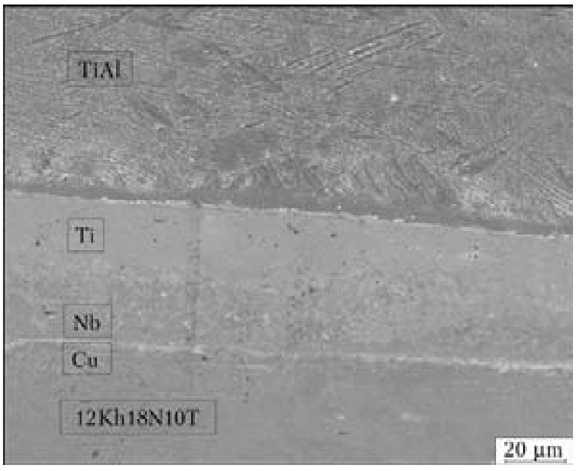

Figure 1. Microstructure (×600) of the zone of the joint of γ-TiAl to 12Kh18N10T steel with application of solid interlayers (titanium, niobium, copper)

material [8]. A large number of defects were found in the joint zone. Based on our results, sound welded joints of γ-TiAl can be obtained at higher values of temperature (approximately, 1200 °C), that is in agreement with the data of [9].

As such different materials as intermetallic alloy and copper interlayer, differing by their physico-chemical properties, are being joined, welding of γ-TiAl intermetallic to 12Kh18N10T steel was performed in two stages. At the first stage interlayers of titanium and niobium were welded to the intermetallic at 1200 °C, and at the second stage stainless steel was joined to the assembly through a copper interlayer at a lower temperature (1000 °C).

Samples of 15 × 15 × 5 mm size were cut out in an EDM machine. Table 2 gives the characteristics of interlayers used in welding. Samples were welded in unrestrained state.

Microstructure of the VD-welded joint, made by of γ-TiAl intermetallic alloy to 12Kh18N10T steel through interlayers of titanium, niobium and copper, is given in Figure 1. Metallographic investigations showed that in the zone of γ-TiAl/Ti/Nb+ Cu/12Kh18N10T joint such defects as cracks and pores are absent. As follows from Figures 1 and 2, active diffusion processes with formation of a wide zone of bulk interaction from the γ-TiAl side take place in the joint zone during welding.

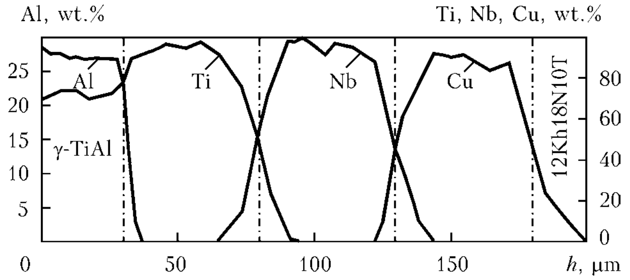

Figure 2. Element distribution in the zone of the joint of γ-TiAl to 12Kh18N10T steel with application of solid intermediate interlayers from titanium, niobium and copper: *h* — interlayer thickness

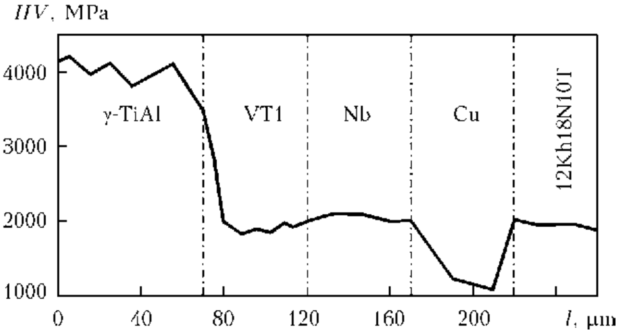

Figure 3. Distribution of microhardness across the zone of γ-TiAl + 12Kh18N10T joint made with application of interlayers from titanium, niobium and copper

At investigation of microhardness distribution in the zone of γ-TiAl + 12Kh18N10T joint (Figure 3) it was established that an increase of microhardness up to 4050 MPa was noted on the boundary of γ-TiAl intermetallic–titanium interlayer. In this region 8.95 at.% Al is found due to aluminium diffusion from the intermetallic towards titanium.

An abrupt lowering of microhardness (to 1100 MPa) was found from the side of stainless steel on the boundary with copper interlayer, which corresponds to microhardness value of copper. It is obvious that a critical point in terms of performance of γ-TiAl/Ti/Nb + Cu/12Kh18N10T welded joint is the region of copper location, where microhardness values are 2 times lower than in the adjacent sections.

Nanolayer of Ti–Al type of total thickness of 20 μm and thickness of individual layers of aluminium and titanium of approximately 20 nm was used to equalize microhardness in the joint zone from the intermetallic side (see Table 2), that ensures additional activation of the surfaces being welded.

It should be also noted that at slow heating of nanolayered Ti/Al interlayers at 50 °C/min rate, characteristic for VDW, the following sequence of phase transformations was recorded: $Al_3Ti \rightarrow Al_5Ti_2 \rightarrow Al_2Ti \rightarrow AlTi$ [10]. In nanolayered interlayers diffraction indications of Ti_3Al intermetallic formation are absent. Formation of diffusion layer of Ti/Al composition more ductile than Ti_3Al, between the inter-

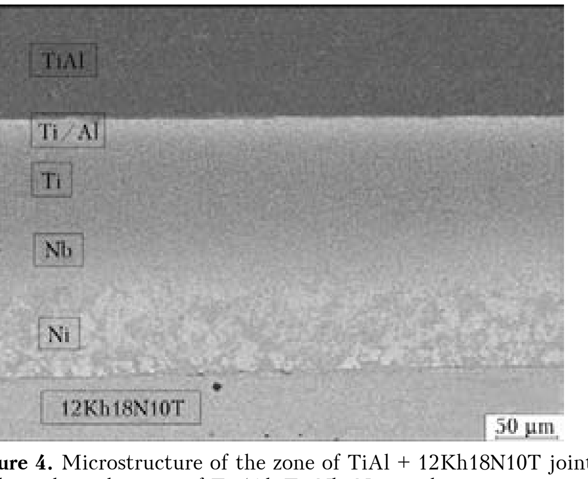

Figure 4. Microstructure of the zone of TiAl + 12Kh18N10T joint made with application of Ti/Al–Ti–Nb–Ni interlayers

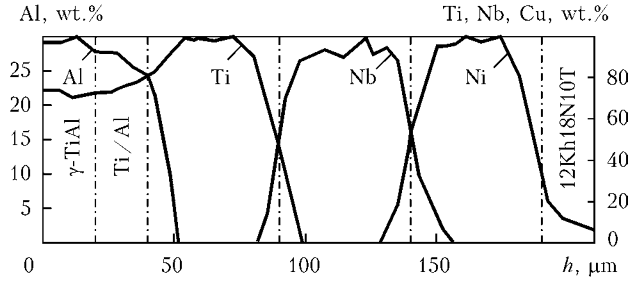

Figure 5. Element distribution in the zone of TiAl + 12Kh18N10T joint made with application of Ti/Al–Ti–Nb–Ni interlayers

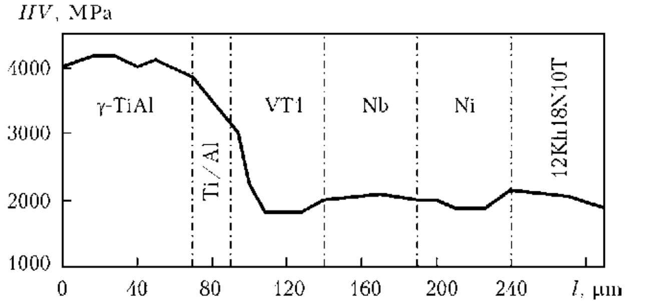

Figure 6. Microhardness distribution across the zone of γ-TiAl + 12Kh18N10T joint made with application of Ti/Al–Ti–Nb–Ni interlayers

metallic alloy and titanium interlayer during welding, can have an essential influence on improvement of welded joint quality [6].

Ti/Al type interlayer was placed between the intermetallic and titanium interlayer. Nickel interlayer was inserted between steel and niobium, as its diffusion mobility in iron and its strength characteristics are higher than those of copper (see Table 1).

In Nb–Ni pair a latent period is in place at intermetallic formation. So, at 1000 °C time of formation of an intermetallic of approximately 1.5 μm thickness is equal to 11 min [11].

Welding was conducted in two stages: intermetallic was joined to Ti/Al–Ti–Nb interlayers at T_w = = 1200 °C, P_w = 40 MPa, t_w = 20 min with subsequent welding of an interlayer of nickel and 12Kh18N10T steel at T_w = 1000 °C, P_w = 20 MPa, t_w = 10 min.

Metallographic examination of the joints showed that there are no welding defects in the butt. As is seen from welded joint microstructure (Figure 4) and element distribution (Figure 5), diffusion processes proceed actively in the butt during welding, leading to formation of bulk interaction zones between the intermetallic and titanium, as well as niobium and titanium. Analysis of microhardness values in the zone of γ-TiAl–Ti/Al–Ti–Nb–12Kh18N10T joint (Figure 6), made by VDW, showed that the nature of microhardness distribution is more uniform than in welding with Ti–Nb–Cu interlayers.

CONCLUSIONS

1. Considering the differences in physico-chemical properties of welded materials, a two-stage schematic of welding γ-TiAl to 12Kh18N10T steel was proposed.

2. In joints made by VDW of intermetallic γ-TiAl alloy to 12Kh18N10T steel through Ti–Nb–Cu interlayers an abrupt lowering of microhardness values on the copper interlayer is noted.

3. Application of nickel instead of the copper interlayer in welding γ-TiAl to 12Kh18N10T steel allows producing sound welded joints at uniform distribution of microhardness in the butt.

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