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APPLICATION OF ULTRAFINE NICKEL POWDER FOR DIFFUSION JOINING OF TITANIUM TO STAINLESS STEEL

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The paper deals with the features of joining titanium alloy PT-3V to steel 08Kh18N10T by diffusion welding with application of an interlayer of ultrafine nickel powder, produced by thermal decomposition of nickel formate $Ni(COOH)_2$ + + $2H_2O$. Comparison of the structures of welded joints of these materials for presence of intermetallic phases in welding without interlayers and with a nickel interlayer at different mode parameters was performed. Application of ultrafine nickel powder at temperatures of 965 and 890 °C leads to formation of a continuous layer of solid intermetallics. At the temperature of 790 °C the diffusion zone has a multilayer structure, differing from the microstructure of steel-titanium joint, produced without the nickel interlayer. Mechanical rupture testing of the welded joints showed that sufficient strength properties are achieved at application of an interlayer of ultrafine nickel powder at lower temperature and pressure, preventing intensive growth of intermetallics. The highest values of ultimate strength were achieved at welding temperature of 760–790 °C and were equal to 346 MPa on average. 13 Ref., 3 Tables, 4 Figures.

Keywords: *diffusion welding, interlayer, ultrafine powder*

An urgent task for industry always is joining parts and assembly units, manufactured from dissimilar materials, into serviceable components, for instance of «α-titanium alloy + stainless steel 08Kh18N10T» combination by diffusion welding method. It is known [1–4] that joining titanium alloys to alloys containing nickel, involves certain difficulties [5–7] because of formation of intermetallics between these two elements [8]. It is understandable that in order to achieve the required service properties of welded joints, diffusion welding should be conducted under the conditions, limiting formation of intermetallic phases in the diffusion zone of the welds. In other words, the welding process should be realized at temperatures below those of the start of intermetallic formation [9–11]. Naturally, there arises the need for application of interlayers, and not just for elimination of formation of intermetallics in the joint zone, but also for lowering the welding temperature and pressure, this way not promoting their growth. Such an ambiguous task can be solved with application of interlayers in the form of highly-reactive high-energy powder materials, providing:

- considerable lowering of thermodeformational impact on the materials being welded;
- intensification of running of diffusion processes at abruptly lowered temperatures;
- preservation of initial properties of these materials;
- sufficient mechanical strength of welded joints of dissimilar materials [11–13].

In welding of dissimilar metals and alloys nickel is often used as interlayer that is due to its favourable physicochemical properties and good metallurgical compatibility with the majority of metals [3–7]. Investigations of diffusion welding with application of interlayers from various nickel powders with different dispersity: *d* — electrolytical (PNE-1, $d = 39.75$ μm), carbonyl (PNKOT-1, $d = 7.63$ μm) and ultrafine, produced by thermal decomposition of nickel formate $Ni(COOH)_2 + 2H_2O$ ($d < 0.01$ μm) showed that maximum strength is achieved in welding through ultrafine powder (UFP) [7, 11, 13]. This powder has minimum particle size, and the size of specific surface can be regulated at pyrolysis of nickel formic acid and can reach 20 m^2/g. A greater value can be also achieved, but UFP becomes pyrophoric and, naturally, difficult to work with. Moreover, this UFP features purity of the product and absence of impurities.

Application of nickel UFP allows lowering welding temperature to values, partially or completely eliminating formation of brittle intermetallic inclusions or liquid eutectics between the materials being joined. This factor is responsible for producing diffusion joints with high mechanical properties [3–5, 7, 11].

The paper gives the results of experimental studies on optimization of the technology of diffusion welding of austenitic steel 08Kh18N10T to titanium alloy PT-3V through an interlayer of nickel UFP and presents the results of metallographic examination of welded joints and mechanical tensile testing of welded samples. Tables 1, 2 give the chemical composition of the studied materials.

The main objective of the work was producing diffusion welded joints with high stable mechanical properties without inadmissible internal defects while ensuring lowering of the joining process temperature.

Table 1. Chemical composition of alloy PT-3V, wt.%

Elements	Ti	Fe	V	Al	Zr	Si	C	N	Res.
Content	91.39–95.0	up to 0.25	1.2–2.5	3.5–5.0	up to 0.3	up to 0.12	up to 0.1	up to 0.4	0.45

Table 2. Chemical composition of 08Kh18N10T, wt.%

Elements	Ti	Fe	Cu	Cr	P	S	Ni	Mn	Si
Content	0.4–1.0	67	up to 0.3	17–19	up to 0.035	up to 0.02	9–11	up to 2	up to 0.8

Used as an interlayer was nickel UFP, rolled into a strip 60 μm thick with 55 % porosity. Size of particles of initial nickel UFP (main fraction) is less than 0.01 μm, specific surface of the powder is about 17 m^2/g. After rolling UFP into a strip only the value of specific surface of the powder changes, but by not more than 8 %. But the strip ensures producing welds of uniform thickness and density, and at the same time allows realizing an extremely large margin of free energy of powder particles, from which it consists [7, 11–13].

Experiments were conducted on cylindrical samples from titanium alloy PT-3V and steel 08Kh18N10T of 20 mm diameter and 30 mm height each. Welding was performed in a diffusion welding unit SDVU-50 with radiation heating, providing vacuum not lower than $5\cdot10^{-5}$ mm Hg.

A strip from nickel UFP was placed between the materials being joined.

During experiments, welding temperature *T* and soaking time *t* were varied, and welding pressure *P* = = const = 27.5 MPa.

Produced blank was used to cut out a sample for metallographic examination, which was conducted in Neophot microscope at ×250 magnifications. Then parts for mechanical tensile testing by a standard procedure were cut out of the studied samples.

Authors of works [2, 9] considered the features of phase formation when joining steel 08Kh1810T to PT-3V alloy by diffusion welding directly, without interlayers. Proceeding from studies of the microstructure of this joint (Figure 1), it is shown that the joint zone is characterized by presence of an interlayer of intermetallics formed between titanium and iron at *T* = 965 °C for 1 min. This mode ensures the strength of the joint of about 255 MPa that is almost by 100 MPa lower than the required value at operation of this component.

In this study analysis of the influence of an interlayer from nickel UFP on the strength of welded joint through growth of intermetallic phases at different temperatures of diffusion welding was performed. Table 3 gives sample numbers, their joining modes and results of rupture testing. Temperature of welding samples No.2 and No.3 corresponded to that of welding sample No.1, as it was necessary to evaluate the influence of nickel UFP layer on welded joint strength. As one can see, in this case the strength is much lower than in welding without the interlayer. In [11] it is shown that this is related to high diffusion activity of nickel UFP. The other experimental temperatures (890 and 790 °C) are taken from critical points of Ni–Ti constitutional diagram, and temperature of 760 °C is the temperature at which no sound joint of alloys PT-3V and 08Kh18N10T without the interlayer can form, and the joint with an interlayer has σ_t = 355 MPa.

Metallographic examination of welded joints produced by diffusion welding of austenitic steel and titanium alloy through a layer of nickel UFP, revealed their multilayer structure (Figure 2). They differ from the microstructure given in Figure 1.

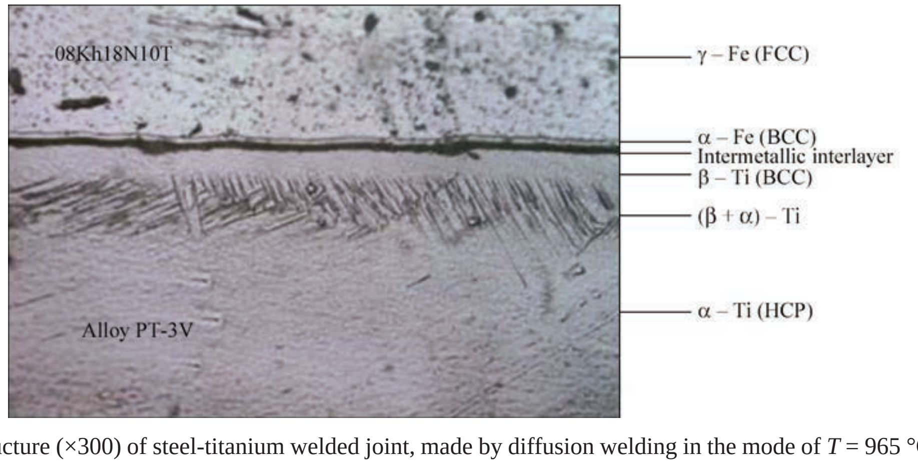

Figure 1. Microstructure (×300) of steel-titanium welded joint, made by diffusion welding in the mode of *T* = 965 °C, *t* — 1 min without application of interlayers [2, 9]

Table 3. Samples made by diffusion welding through a layer of nickel UFP and without it

Sample number	Presence of an interlayer	Temperature T, °C	Welding time, t, min	σ_t, MPa
1	No layer	965	1	255
2	UFP	965	1	150
3	UFP	965	3	140
4	No layer	890	1	250
5	UFP	890	3	53
6	UFP	790	10	349
7	UFP	790	5	311
8	UFP	790	20	311
9	UFP	790	15	307
10	UFP	760	15	355

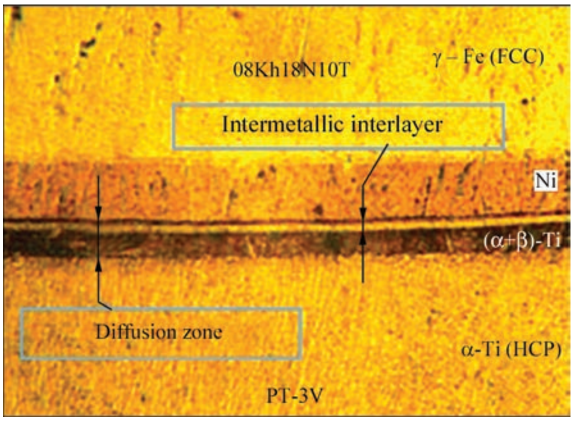

Figure 3. Microstructure of metal (×250) of a welded joint of austenitic steel with titanium alloy, made by diffusion welding at 790 °C, 10 min, through an interlayer from nickel UFP

Welding at 890 °C, 1 min and at 965 °C, 1 min. leads to formation of a phase, which, according to Ti–Ni constitutional diagram, is an intermetallic Ti_2Ni phase (Figure 2, *a*, *b*). Thickness of this phase reached 14 and 22 μm, respectively. Increase of soaking time up to 3 min leads to appearance of eutectic phase Ti_2Ni + + α + β of up to 128 and 152 μm thickness, respectively (Figure 2, *c*, *d*).

Microstructure of the metal of joints produced by welding at 760 and 790 °C with soaking for 5–20 min (Figures 3, 4) has the following features:

• a nickel layer on average 40 μm thick, containing pores, is observed from the steel side;

• α-Fe and β-Ti phases characteristic for diffusion joint of steel with titanium without UFP interlayer, are absent that is indicative of the absence of interdiffusion of elements of steel and titanium alloy through a layer of nickel, i.e. diffusion joint formed over a layer of nickel;

• a diffusion zone is observed between the nickel layer and titanium alloy, which includes intermetallic phase Ti_2Ni up to 12 μm thick, interdiffusion zone up to 10 μm thick and (α + β)-Ti layer up to 30 μm thick, formed as a result of nickel diffusion into titanium.

One can see from Table 1 that interlayer application at the temperature of 965 and 890 °C was detrimental for welded joint strength, compared to the results of welding without interlayer application. Samples, welded at temperatures of 760–790 °C, have ultimate strength equal to 346 MPa on average. This is attributable to minimum zone of intermetallic inter-

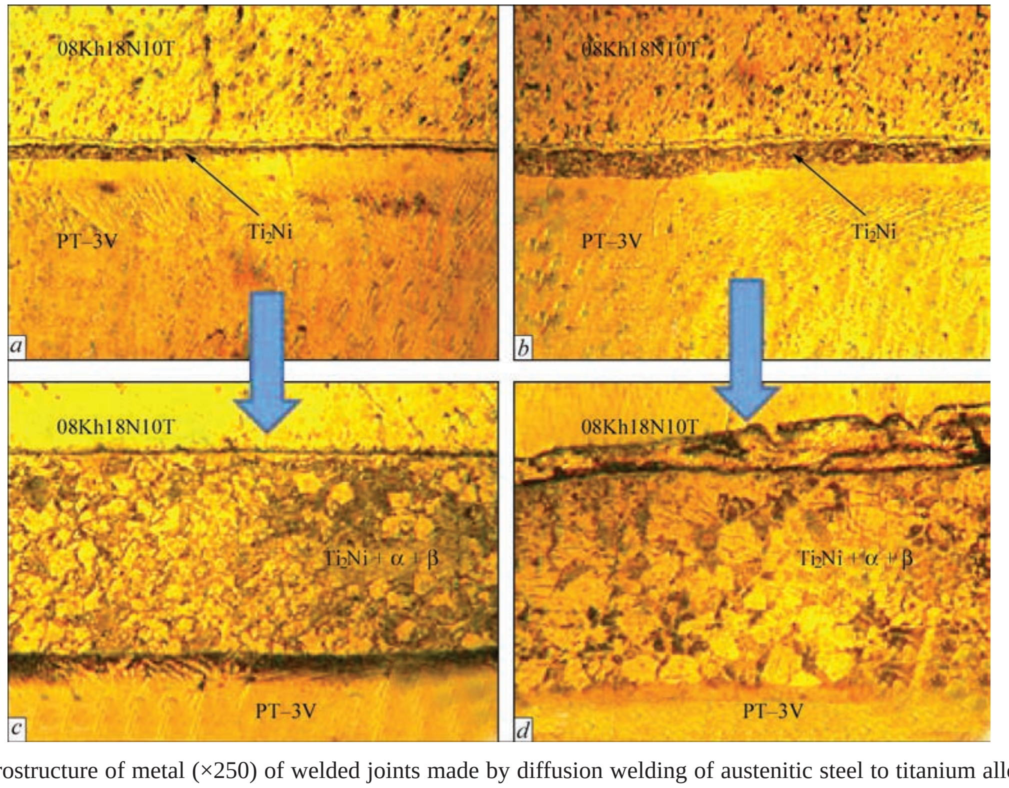

Figure 2. Microstructure of metal (×250) of welded joints made by diffusion welding of austenitic steel to titanium alloy through an interlayer from nickel UFP in the following modes: *a* — 890 °C, 1 min; *b* — 965 °C, 1 min; *c* — 890 °C, 3 min; *d* — 965 °C, 3 min

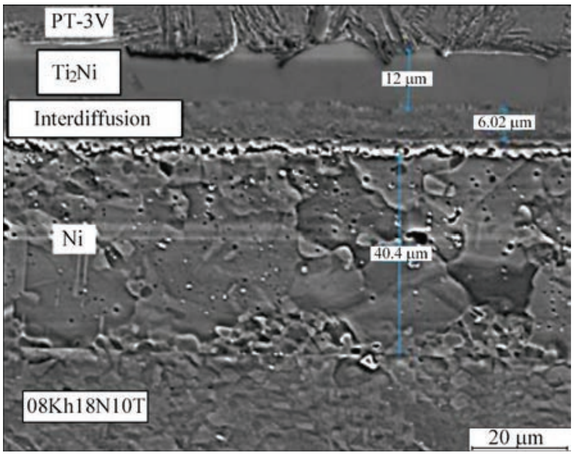

Figure 4. Microstructure of metal in welded joint of austenitic steel with titanium alloy, made by diffusion welding at 760 °C, 15 min through an interlayer from nickel UFP

layer in the welded joint and long-term interdiffusion of the materials being joined.

Conclusions

1. Application of nickel UFP at temperatures of 965 and 890 °C leads to formation of a continuous layer of solid intermetallics. At the temperature of 790 °C the diffusion zone has a multilayer structure, differing from that of steel-titanium joint, produced without the nickel interlayer. A wide nickel layer is observed from the steel side, and a layer of (α + β)-Ti – from the titanium side.

2. Mechanical tensile testing of welded samples showed that the highest values of ultimate strength were achieved at welding temperatures of 760–790 °C, and were equal to 346 MPa on average.

3. Performed work confirms the positive effect from application of highly-reactive nickel UFP in welding titanium to steel. It becomes possible to conduct welding at temperatures of 760–790 °C, avoiding formation of brittle intermetallic phases directly between alloys PT-3V and 08Kh18N10T. Intermetallic layers, formed between the interlayer and titanium alloy at the temperature of 760 °C, have no decisive impact on welded joint strength.

1. Kazakov, N.F. (1976) *Diffusion welding of materials*. Moscow, Mashinostroenie [in Russian].
2. Uvarov, A.A. Semenov, A.N., Krestnikov, N.S. et al. (2017) Examination of structure of steel-titanium welded joints, produced by diffusion welding using ultrafine nickel powders. *Metallovedenie i Termich. Obrab. Metallov*, **8**, 57–61 [in Russian].
3. Kireev, L.S., Zamkov, V.N. (2002) Solid-state joining of titanium to steel (Review). *The Paton Welding J*., **7**, 29–35.
4. Ustinov, A.I., Falchenko, Yu.V., Melnichenko, T.V. et al. (2015) Vacuum diffusion welding of stainless steel through porous nickel interlayers. *Ibid.*, **7**, 3–9.
5. Bachin, V.A., Kvasnitsky, V.F., Kotelnikov, D.I. et al. (1991) *Theory, technology and equipment for diffusion welding*. Moscow, Mashinostroenie [in Russian].
6. Karakozov, E.S. (1976) *Solid-state joining of metals*. Moscow, Metallurgiya [in Russian].
7. Lyushinsky, A.V. (2006) *Diffusion welding of dissimilar materials*. Moscow, Akademiya [in Russian].
8. Khansen, M., Anderko, K. (1962) *Structures of binary alloys*. Vol. 1, 2. Moscow, Metallurgiya [in Russian].
9. Uvarov, A.A. Semenov, A.N., Novozhilov, S.N. et al. (2014) Technology of manufacture of bimetal transition pieces from austenitic steel-α-titanium alloy. *Svarochn. Proizvodstvo*, **4**, 34–36 [in Russian].
10. Rodin, M.E., Semenov, A.N., Plyshevsky, M.I. et al. (2008) Investigation of mechanical properties of corrosion-resistant steel welded joints with titanium alloys. *Ibid*., **6**, 9–11 [in Russian].
11. Lyushinsky, A.V., Mazanko, V.F., Belyakova, M.N., Vorona, S.P. (1999) Mass transfer in pressure welding using ultrafine nickel powders. *Ibid*., **6**, 10–14 [in Russian].
12. Lyushinsky, A.V. (2013) *Modern welding technologies. Engineering-physical principles*. Moscow, ID Intellekt [in Russian].
13. Lyushinsky, A.V. (2001) Criteria of selection of interlayers in diffusion welding of dissimilar materials. *Svarochn. Proizvodstvo*, **5**, 40–43 [in Russian].

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