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FILLER FLUX-CORED WIRE FOR TIG WELDING AND SURFACING OF VT22 TITANIUM ALLOY

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The paper considers an approach for selection of filler material in TIG welding of VT22 titanium alloy. It is shown that weld metal produced using pilot flux-cored wire PPT-22 is a representative of transient class of titanium alloys, to which VT22 alloy is referred (coefficient of β-stabilizing of such metal equals to 1). This wire can be used for argon-arc welding of high-strength VT22 titanium alloys. Mechanical properties of such welded joints after heat treatment reach the level of base metal indices. Application of PPT-22 wire in restoration argon-arc surfacing of VT22 alloy parts provides their high service characteristics. 15 Ref., 4 Tables, 5 Figures.

Keywords: *VT22 titanium alloy, flux-cored wire, TIG welding, restoration surfacing*

Mechanical characteristics of welded joints of high-strength titanium alloys, in particular of the VT22 alloy, are significantly lower than those of base metal. Therefore, to compensate a low strength and ductility of weld metal, the designed thickening of metal in the weld zone is used. This in turn leads to a significant increase in material consumption and cost of welded products. Therefore, the producing of welded joint of equal strength is an urgent task.

Due to the nature of effect of different alloying elements on titanium, the commercial alloys are divided by the type of structure into the following groups: α-alloys, pseudo-α-alloys (alloys based on α-phase with a small amount of β-phase), (α + β)-alloys, pseudo-β-alloys (alloys based on the β-phase with a small amount of α-phase) and β-alloys. The authors of works [1, 2] also distinguish alloys of a transition class, which according to the structure and transformations occurring in them, occupy an intermediate position between (α + β)- and pseudo-β-alloys, to which the VT22 alloy belongs (Table 1).

For titanium alloys [1, 2], a conception about the β-stabilizing factor K_β was introduced. This coefficient represents a sum of relations of the concentration of each β-stabilizer in the alloy to its second critical concentration in a binary titanium alloy with this element [3].

When describing the multicomponent titanium alloys, it is assumed that the effect of all β-stabilizers can be expressed by the total equivalent content of molybdenum $[Mo]_{eq}$. Based on the data of works [4–6], the authors of the work [3] expressed the following relation for evaluating the equivalent of titanium alloys by molybdenum, wt.%:

$$[Mo]_{eq} = Mo + Ta/4 + Nb/3.3 + W/2 + V/1.4 + Cr/0.6 + Ni/0.8 + Mn/0.6 + Fe/0. \quad (1)$$

and the coefficient of β-stabilization is determined by the formula:

$$K_\beta = [Mo]_{eq}/C_{cr\,Mo} = [Mo]_{eq}/11. \quad (2)$$

where $C_{cr\,Mo}$ is the critical concentration of Mo in the binary titanium alloy with it and is equal to 11 %.

According to the type of structure (β-stabilization coefficient), titanium alloys are distributed in the succession, presented in Table 2 [1, 7, 8].

For today, there is a number of wires based on titanium, which are manufactured by industry. Solid wires on the base of titanium with an ultimate strength of more than 800 MPa (Table 3) do not provide a

Table 1. Chemical composition of VT22 titanium alloy, wt.% (GOST 19807–91)

Ti	Al	V	Mo	Fe	Cr	[O]	[H]	[N]
Base	4.4–5.7	4.0–5.5	4.0–5.5	0.5–1.5	0.5–2.0	Not more than 0.18	Not more than 0.015	Not more than 0.05

Table 2. Values of β-stabilization coefficient for titanium alloys

Classification parameter	Class of titanium alloy					
	α-	Pseudo-α	(α+β)	Transition	Pseudo-β	β
K_β	0	<0.25	0.3–0.9	1.0–1.4	1.5–2.4	2.5–3.0

Table 3. Chemical composition and mechanical properties of titanium-based wires with an ultimate strength of higher than 800 MPa (GOST 27265–87)

Wire grade	Content of alloying elements, wt.%					Mechanical properties	
	Al	Mn	Mo	V	Zr	σ_t, MPa	δ, % (not lower than)
VT6sv	3.5–4.5	–	–	2.5–3.5	–	665–865	12
SPT-2	3.5–4.5	–	–	2.5–3.5	1–2	645–845	13
VT20-2sv	3.5–4.5	–	0.5–1.5	0.5–1.5	1–2	635–835	10
SP15*	3.0–5.5	–	2.0–3.5	2.0–3.5	1–2	Not lower than 735	10

*The share of niobium in this alloy amounts to 2.5–4.4 wt.%.

sufficient complex of mechanical properties during welding of VT22 titanium alloy. The welds produced by TIG welding with the use of wire SPT-2 do not provide the strength of a weld higher than 800 MPa and, therefore, it cannot be used as a filler material for welding alloys with an ultimate strength of higher than 800 MPa. The closest to the VT22 alloy as to the chemical composition and mechanical properties is the wire SP15. However, the use of this wire as a filler material does not provide the equal strength of welded joints of VT22 titanium alloy.

Investigations of the quality of solid wire of the VT22 alloy allowed making the conclusions about the inappropriateness of its use in welding and surfacing due to a large number of defects both on its surface and inside the metal itself, which as a result causes contamination of the weld metal [9].

To solve the problem of welding high-strength titanium alloys, at the E.O. Paton Electric Welding Institute of the NAS of Ukraine a filler material based on the titanium alloy of the system Ti–Al–V–Mo–Nb–Zr was proposed [10]. This invention represents a flux-cored wire containing a metallic component and a flux one, which contains fluorides of alkaline earth and rare earth elements in a ratio 2:1 and in the amount of 6–18 wt.%, and the wire sheath is made of titanium.

The alloy proposed by the authors of the patent [10] (Table 4) is in the range of the chemical composition of the commercially produced alloy SP15 and differs from the VT22 alloy by a degree of alloying. In this regard, during the development of flux-cored wires for TIG welding of VT22 titanium alloy, the VT22 alloy was used as the metallic component of the wire core.

Table 4. Calculated content of alloying elements, wt.%

Element	C_{wire}, %	C_{VT22}, %*	C_{weld}, %
Al	3.2	5.1	4.5
Mo	2.9	4.8	4.2
V	2.8	4.8	4.2
Fe	0.4	1.0	0.8
Cr	0.6	1.3	1.1

*Average value according to GOST 19807–91.

To determine the degree of alloying of the weld metal by the flux-cored wire, the following calculation formula was proposed:

$$C_{weld} = K_1 C_{wire} + K_2 C_{VT22}. \quad (3)$$

where K_1, K_2 are the coefficients of the share of alloying elements in the wire and in the VT22 alloy, respectively; C_{wire} is the concentration of alloying elements in the wire; C_{VT22} is the concentration of alloying elements in the VT22 alloy (average value).

During determination of the coefficients K_1 and K_2, the macrosection of the welded joint of the VT22 alloy with a thickness of 8 mm was used, on which the cross-sectional area of the weld metal and the metal in the groove was determined (Figure 1). Based on the ratio of the cross-sectional area of the weld to the area of the metal produced by the wire, the coefficients K_1 and K_2 are equal to the values 0.3 and 0.7, respectively.

For the wire of a diameter of 3.0 mm with a filling coefficient of 64 % (the share of the flux component with respect to the metal one amounts to 7 %), the sheath of pure titanium amounts to 36 % with respect to the wire. At the same parameters of the wire, the amount of pure titanium in the metallic component of the VT22 alloy is 48 %, the volume of pure titanium in the wire is 83 % and of the alloying elements in the wire is 10 %. Based on the ratio of the total amount of alloying elements in the VT22 alloy to the total amount of alloying elements in the wire, the amount of each alloying element in the wire with regard to the sheath of

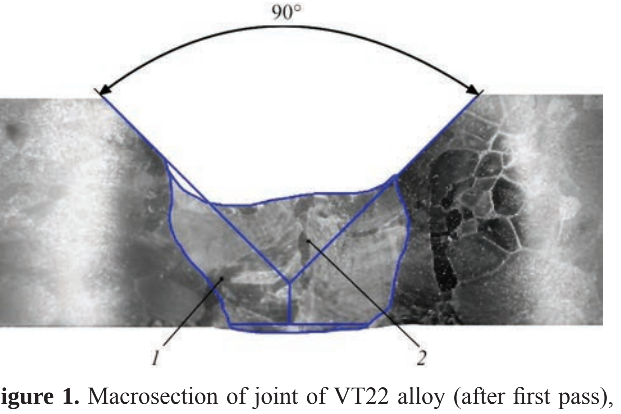

Figure 1. Macrosection of joint of VT22 alloy (after first pass), produced by experimental flux-cored wire: *1* — weld metal; *2* — metal in the groove

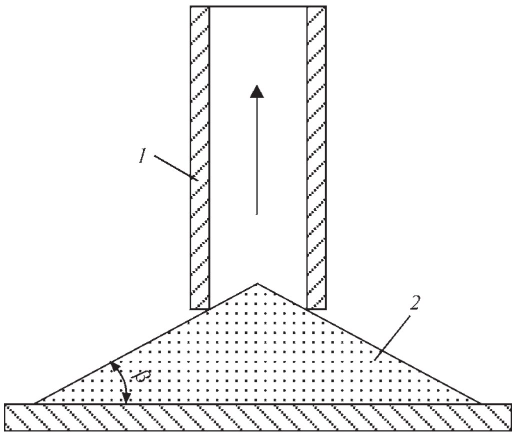

Figure 2. Scheme for determining natural angle of slope: *1* — hollow cylinder; *2* — bulk mixture

pure titanium was determined by the calculation method. The obtained data on the amount of each alloying element allowed determining their concentration in the weld (Table 4), and also calculating the molybdenum equivalent ($[Mo]_{eq} = 11.1$). The weld metal of a welded joint of VT22 titanium alloy produced using filler flux-cored wire, which includes the metallic component of the VT22 alloy, has a β-stabilization coefficient equal to 1, which refers such a metal to the alloys of a transition class, to which VT22 titanium alloy belongs.

A similar calculation was also made for the wire, proposed by the authors of the patent [10], i.e. with a metallic component corresponding to the chemical composition of the alloy SP15, however, in this case $K_\beta = 0.9$, which refers such a metal to the class of ($\alpha + \beta$)-titanium alloys.

Welded joints of high-strength titanium alloys should be obligatory subjected to heat treatment to increase their mechanical properties. Since the weld metal and the base metal in combination with the use of flux-cored wire with a charge of SP15 alloy are representatives of a different class, it is necessary to apply different heat treatment conditions for the weld metal and base metal, which is almost impossible to realize in practice. Therefore, as a metallic component in flux-cored wire it is advisable to use granules of the alloy of the same chemical composition as in the alloy subjected to welding, i.e. VT22.

An increased sliding of spherical granules along the length of the wire leads to their spilling and spattering during welding. This in turn has a significant effect on the process of arc burning, on the formation of a weld and its chemical composition. As was shown by the investigations, using the wire with granules of a spherical shape, the amount of alloying elements in the weld metal decreases by 2–3 times. The spherical surface of granules also has a low adhesion to the flux introduced into the core.

In order to change the shape of granules, a complex of devices was developed. To evaluate the quality of flux-cored wire, the degree of granules deformation was investigated, which was determined by measuring the natural angle of a slope (β) (Figure 2). For this purpose, the hopper was previously lowered until the contact with the plane and the mixture was poured into it. Then the hopper was lifted at a constant speed (10 m/h), and the mixture, which was poured, formed a cone.

At certain modes, such a shape of granules ($\beta = 30°$) was achieved, at which they did not spill out of the formed tube (using granules of a spherical shape, where $\beta = 20°$).

In the experimental way the flux component of the wire was determined, which is represented by a three component system CaF_2–SrF_2–BaF_2. To obtain the mechanical properties of the weld metal close to the base metal, it is necessary to have the maximum amount of metallic component and the minimum amount of flux component in the charge of a flux-cored wire. It was established experimentally that the use of a flux in the amount of 7 % prevents the formation of pores in the weld, and the slag formed after welding, spalls off well.

As a sheath of the flux-cored wire, a strip of VT1-00 titanium alloy was used. The formation of flux-cored wire and its drawing to the required diameter was carried out in a special drawing bench [11] intended for manufacturing of titanium flux-cored wires (Figure 3).

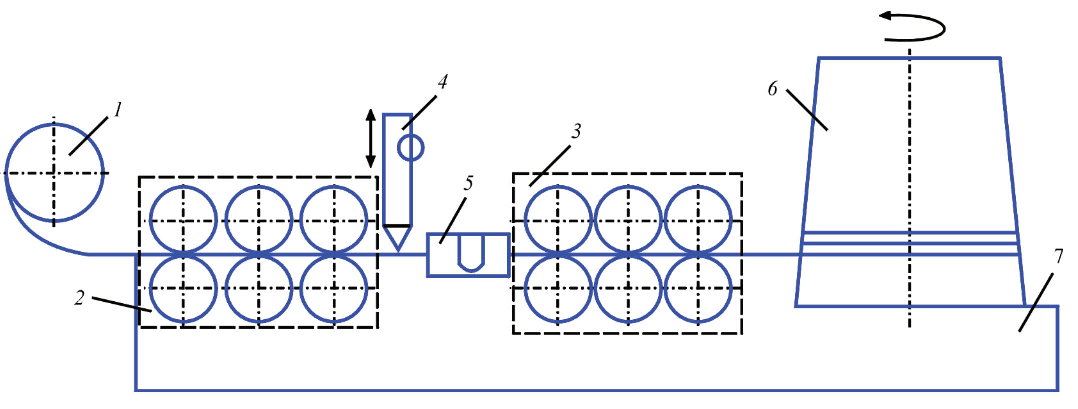

Figure 3. Scheme of drawing bench: *1* — cassette; *2* — roller stands for the formation of U-shaped profile; *3* — roller stands for closing the tubular profile and the primary compaction of the charge; *4* — batcher; *5* — U-shaped strap; *6* – drum; *7* — bed

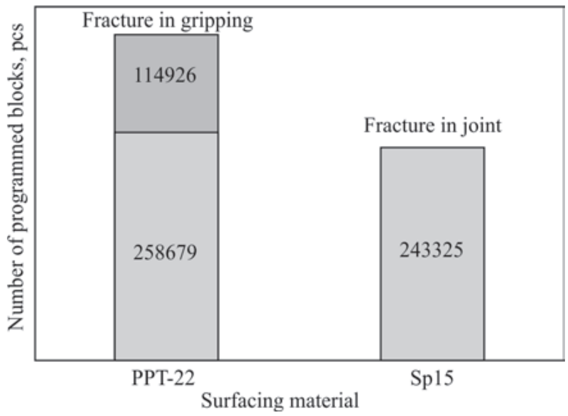

Figure 4. Test results of deposited joints for fatigue strength

According to the results of the experiments, a pilot flux-cored wire PPT-22 with a charge of optimized composition was manufactured. The measurements carried out along the entire length of the manufactured wire showed the constancy of the filling coefficient equal to 0.61 ± 0.03 at a wire diameter of 3.0 mm.

The experimental surfacing using the produced wire showed a stable preceding of the welding process (without spilling of nonmelted granules), which indicated a sufficient compaction of the charge and its uniform distribution along the wire length.

The use of the wire PPT-22 as a filler material in MIAB welding of VT22 titanium alloy made it possible to produce welded joints of 8 mm thickness (after heat treatment) with the values of strength (σ_t) and impact toughness (*KCV*) of welded joint at the level of 1120 MPa and 14.5 J/cm^2, respectively. These mechanical properties are close to those of the base metal (σ_t = 1067 MPa, *KCV* = 14.5 J/cm^2) [12].

The wire PPT-22 was also used as a filler material for argon-arc restoration surfacing of parts of the VT22 titanium alloy [13].

After surfacing and local heat treatment, fatigue strength tests were carried out. The test results showed [14] that using the flux-cored wire PPT-22, deposited joints withstood a full cycle of tests according to the preset programs and the fracture after additional cycles occurred at the place of gripping (Figure 4).

The test results of deposited joints for wear resistance under the conditions of fretting corrosion [15] also showed positive results. Thus, a linear wear of deposits, produced applying the wire PPT-22, is almost twice lower than that of the base metal of VT22 (Figure 5).

Thus, at the E.O. Paton Electric Welding Institute of the NAS of Ukraine a titanium filler flux-cored wire PPT-22 was developed, which consists of metallic (VT22 granules) and flux (alkaline earth metal fluoride elements) components, using which the same strength of welded joints of VT22 alloy is achieved during argon-arc welding and a subsequent heat treatment. It is also advisable to use this wire during restoration surfacing of parts made of VT22 alloy.

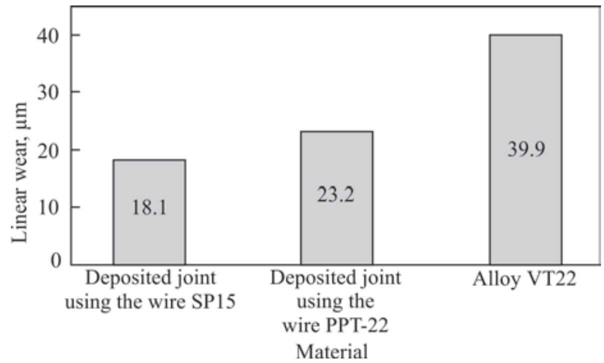

Figure 5. Test results of deposited joints for wear resistance

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