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# INFLUENCE OF RARE-EARTH ELEMENTS ON THE STRUCTURE AND PROPERTIES OF WELDS OF VT22 TITANIUM ALLOY

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The paper presents the results of investigations of the influence of rare-earth metal fluorides on structural changes in weld metal of titanium alloy VT22 for the purpose of using them in the flux filler of experimental flux-cored wire for welding this alloy. It was shown that refinement of β-grains is observed in welds made by argon-arc welding of VT22 alloy over a layer of flux, consisting of rare-earth metal fluorides. Addition of $LaF_3$ to the core of experimental flux-cored titanium wire PPT-22 in combination with heat treatment allowed increasing the impact toughness of welds in argon-arc welding of VT22 alloy 2 times up to 30.6 J/cm$^2$. 8 Ref., 4 Tables, 5 Figures.

***Keywords:*** *VT22 titanium alloy, rare-earth metal, fluorides, flux-cored wire*

Argon-arc welding (AAW) is the most versatile method of joining structures from titanium components, as it allows performing welding in different positions, quickly readjusting the equipment at the change of the joint type and thickness of metal being welded [1, 2]. In view of the high chemical activity, titanium at increased temperatures and particularly in the molten state actively absorbs oxygen and nitrogen, leading to abrupt lowering of ductility. Therefore, welded joint quality is determined, mainly, by reliability of welding zone shielding, and the main difficulty of titanium welding is ensuring reliable shielding from the atmosphere not only of the weld pool and weld root, but also of the cooling areas of welded joint heated above 400 °C, i.e. up to temperatures, at which a noticeable interaction of titanium with gases, namely oxygen, hydrogen and nitrogen, begins.

One of the advantages of welding titanium with flux application is presence of molten flux skin covering the welding zone and protecting it from harmful influence of $O_2$, $H_2$ and $N_2$. During welding, metallurgical reactions are taking place, which may lead to weld enrichment with these impurities. Therefore, one of the requirements to flux systems in titanium welding is absence of oxides in them. It is proved [3] that oxide removal from the fluxes allows limiting oxygen content in the deposited metal below 0.1 %.

Main requirements, made of the flux for titanium welding, are determined, primarily, by comparatively high temperature of titanium melting, so that welding fluxes for it should feature an increased refractoriness [3]. To avoid weld saturation with hydrogen, the flux should have minimum hygroscopicity; provide stability of the arc discharge during welding, and after it is over — easy separation of the slag crust from the solidified weld metal, that is one of the criteria of flux system adaptability to fabrication.



From the viewpoint of adaptability to fabrication, none of the fluorides of alkali and alkali-earth elements is suitable as a one-component flux. Therefore, multicomponent systems, consisting of fluorides of alkali, alkali-earth and rare-earth metals, as well as alkali-earth metal chlorides are applied as fluxes in titanium welding [3].

Application of fluoride fluxes at AAW of titanium leads to reduction of weld pool dimensions, shortening of the time of metal being in the molten state, and also binds hydrogen into $TiF_xH_y$ compounds insoluble in the metal, that lowers the probability of initiation of gas phase nuclei in the weld pool and inhibits pore formation in liquid titanium.

An important property of calcium fluoride in the flux system is its ability to intensively interact with water vapour with formation of hydrogen fluoride. Possibility of removing moisture from the welding zone and, due to that, protection of weld metal from saturation with hydrogen and oxygen, is an important feature of titanium welding using $CaF_2$–based flux. Therefore, the authors selected exactly this component as the base of the flux system.

Experimental method also revealed that a characteristic feature of the slag crust is noted in welding with $BaF_2$. It easily spalls off in whole pieces from the joint surface. For this purpose, it is necessary to add this component to the flux system.

To improve the refractoriness of the flux system, it is necessary to add a component with higher melting temperature (Table 1). It is known [4] that $CaF_2$–$BaF_2$, $CaF_2$–$SrF_2$ and $SrF_2$–$BaF_2$ systems are a continuous row of solid solutions. Among them, $CaF_2$–$SrF_2$ system has the higest melting point. Therefore, transition from two-component $CaF_2$–$BaF_2$ system to $CaF_2$–$SrF_2$–$BaF_2$ system should lead to increased melting temperature of the flux.

Having studied the influence of fluorides of alkali and alkali-earth metals on titanium welding process, the authors selected $CaF_2$–$SrF_2$–$BaF_2$ system, which was the flux base in the core of flux-cored wire PPT-22 for VT22 titanium alloy welding. This wire consists of a sheath from VT1 titanium alloy and core (granules of VT22 alloy and flux component) [5].

Reference [3] is a study of the possibility of weld metal refining by adding to flux such elements active to oxygen and nitrogen, as cerium, lanthanum, yttrium in the form of fluorides. The most active refining action is produced by yttrium, the least active is produced by cerium, with lanthanum taking an intermediate position. It is found that not more than 10 % of these fluorides should be added to the flux to refine the weld metal. Then, oxygen content in the weld metal will be equal to 0.09 % and with further increase of $LaF_3$ or $YF_3$ content in the flux, it will remain constant.

The authors of [6] studied the possibility of modifying the weld metal using fluxes containing fluorides of rare-earth metals. The work shows that in welding of titanium β-alloy VT15 using flux, containing $LaF_3$, refinement of weld structure, improvement of mechanical properties of weld metal and lowering of oxygen content in it are observed. Increase of its ductile properties and impact toughness is noted. Chemical-spectral method showed that metallurgical interaction of liquid metal and molten flux, having $LaF_3$ in its composition, is accompanied by lanthanum transition into the weld metal.

This work is a study of the influence of rare-earth metal fluorides on structural changes in weld metal of VT22 alloy, in order to use them in the composition of flux filler of flux-cored wire PPT-22.

**Features of the influence of rare-earth metal fluorides in welding on structural changes in weld metal of VT22 alloy.** Studies were conducted on welded samples 6 mm thick from VT22 alloy, produced by AAW over flux in one pass and without flux application. Experiments were performed with fluorides of $LaF_3$ and $YF_3$ rare-earth metals in the following mode: $I_w$ = 200 A, $v_w$ = 8 m/h; $L_a$ = 2 mm, $U_a$ = = 12.5–13.0 V.

Comparison of microstructure of the produced deposits showed that in welding over $LaF_3$ and $YF_3$ fluxes the weld shapes do not differ from each other, weld width being 13.5 mm in both the cases. In the weld made by AAW without flux, the maximum penetration depth is 2.5 mm and its maximum is on weld axis; and in the case of AAW over $LaF_3$ and $YF_3$ fluxes penetration is on the same level and is practically the same across the entire weld width (Figure 1).

**Table 1.** Physical properties of flux system components

| Component properties | $CaF_2$ | $SrF_2$ | $BaF_2$ |
|---|---|---|---|
| Temperature, °C | | | |
| melting | 1411 | 1473 | 1280 |
| boiling | 2500 | 2460 | 2260 |
| Density, g/cm³ | 3.18 | 4.18 | 4.83 |
| Heat of formation, kJ/mole | 608 | 1222 | 599.1 |

In all the three variants after welding the weld metal consists of β-phase grains of different dimensions and shape. Most of β-grains have a non-equiaxial form, grain form factor (length-to-width ratio) is equal to 1–5, grains are elongated in the vertical or close to the vertical direction (Figure 2, *a*, *c*, *e*).

It is known [7] that interaxial and interdendrite spaces in the weld metal are enriched in β-stabilizers to a greater degree that the inner volumes of the axes, so that the most intensive decomposition of β-phase occurs in the inner volumes as the least stable regions. The most intensive decomposition of β-solid solution after welding occurred in the weld made by AAW without flux application (Figure 2, *e*). It is obvious that the conditions of cooling of the metal of welds made with application of fluxes, differ from those in welds made without flux application.

Intensity of β-phase decomposition in welds of VT22 alloy depends on the cooling rate after welding, and the higher the cooling rate, the lower is the intensity of decomposition. For instance, metastable β-phase is found in welds of VT22 alloy made by EBW and characterized by very high cooling rate, whereas a significant decomposition of β-phase proceeds in welds, made by ESW and featuring a much lower cooling rate. After AAW with application of yt-

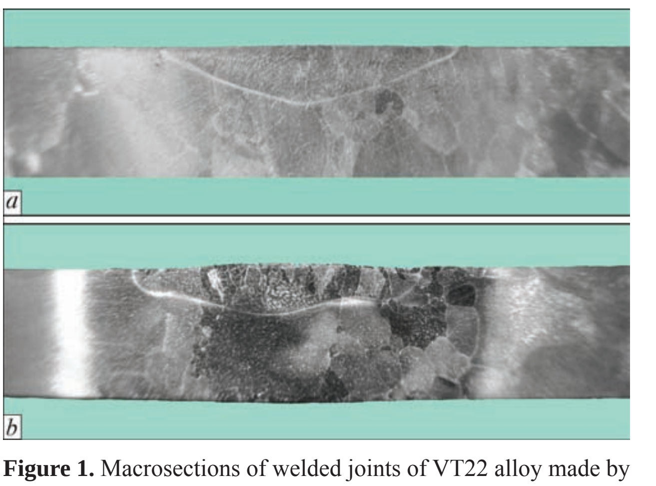


**Figure 1.** Macrosections of welded joints of VT22 alloy made by AAW: *a* — without flux; *b* — over $YF_3$ flux

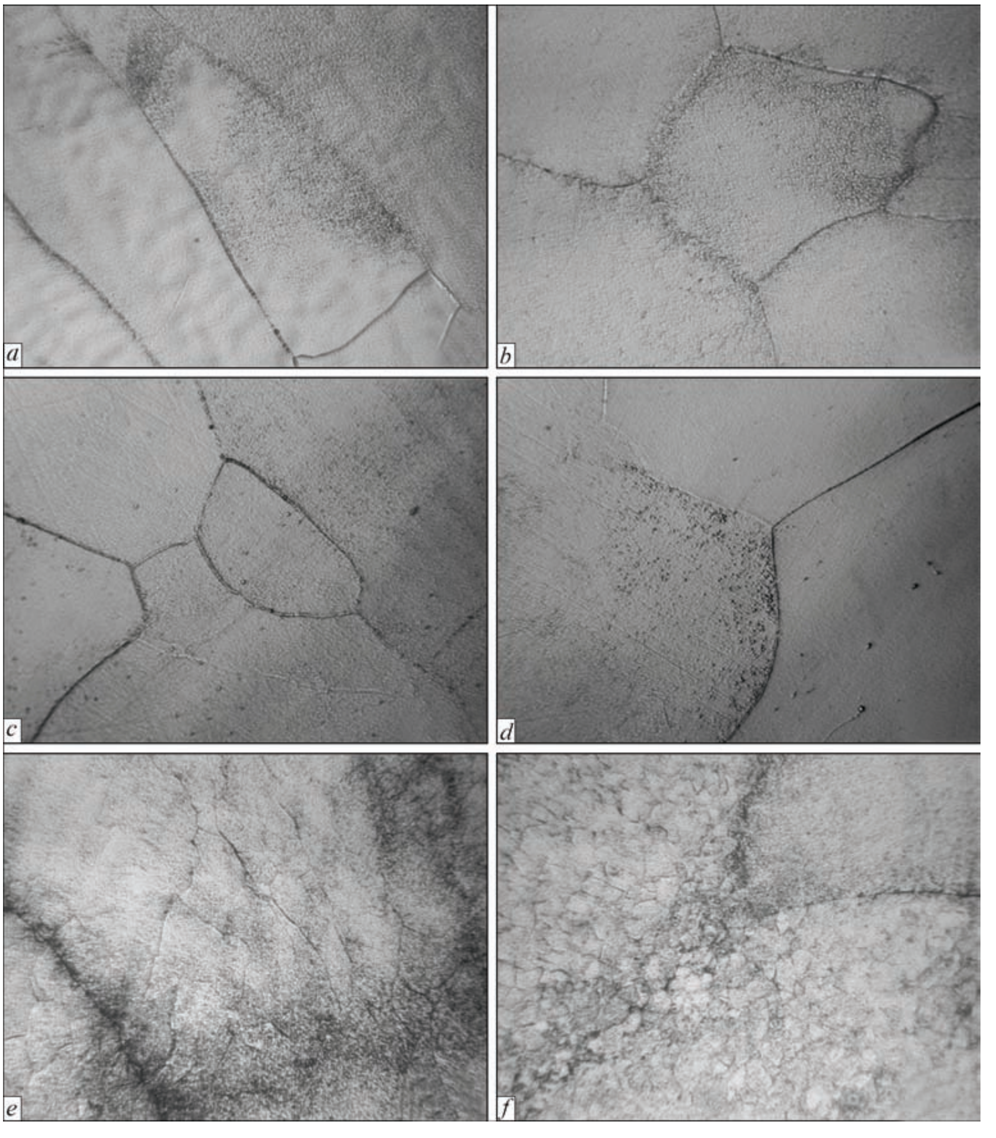

**Figure 2.** Microstructure (×200) of welded joints: *a* — weld made by AAW over $YF_3$ flux; *b* — HAZ of a sample with $YF_3$; *c* — weld made by AAW over $LaF_3$ flux; *d* — HAZ of a sample with $LaF_3$; *e* — weld made by AAW without flux; *f* — HAZ of a sample without flux

trium and lanthanum fluorides, the intensity of β-solid solution decomposition is lower than after AAW without flux. Structure analysis confirms the known fact that the cooling rate of the metal of weld, made with flux application, is higher.

In addition to difference in the intensity of β-phase decomposition in welds, we can note that polygonization processes are very well developed in the weld lower part, particularly, in the HAZ of the sample welded by AAW without flux. Coarse grains of β-phase after AAW without flux application have a developed substructure (Figure 2, *e*, *f*), unlike samples welded by AAW over $LaF_3$ and $YF_3$ fluxes (Figure 2, *a*–*d*). Under the action of welding deformations, individual grain fragments in coarse β-grains rotate relative to each other by an angle of several degrees, forming a substructure.

It should be noted that in welds made by AAW over flux consisting of fluoride of a rare-earth metal ($LaF_3$ or $YF_3$), refinement of β-grains is observed in as-welded condition, compared to AAW without flux application. Analysis of grain distribution in welds over their cross-sectional area showed that the microstructure of the metal of a weld made by AAW without flux application, consists of a small number of large β-grains, and in welds, made with application of fluorides of both yttrium and lanthanum, the number of small grains is much higher than in the weld made without flux application. For instance, in the weld, produced with rare-earth metal fluoride, 10 times more grains of up to 0.1 $mm^2$ area appear, compared to a similar region of the weld, produced without lanthanum or yttrium participation (Figure 3).

Microhardness values (Figure 4) of welds made with $LaF_3$ and $YF_3$ are on the level of 3450 MPa that is 150 MPa higher than those of welds made without addition of rare-earth elements and is closer to microhardness values of base metal (3800 MPa).

**Table 2.** Parameters of sample welding modes

| Pass number | $I_w$, A | $U_a$, V | $v_w$, m/h | $v_w$, m/h |
|---|---|---|---|---|
| 1 | 180 | 10.5 | 9 | 24 |
| 2, 3 | 200 | 12.0 | 9 | 30 |

**Table 3.** Results of mechanical testing of as-welded joints

| Test location | $\sigma_t$, MPa | *KCV*, J/cm$^2$ |
|---|---|---|
| Base metal | 1039.7* | 32.6 |
| Welded joint with $LaF_3$ | 865.3 | 8.9 |
| Weld metal without $LaF_3$ [5] | 1065.1 | 5.9 |
| *The paper gives the results of testing three samples. | | |

Thus, application of rare-earth elements in welding of two-phase ($\alpha + \beta$)-titanium alloy VT22 at weld microhardness values close to those of base metal, leads to refinement of β-grains in the weld, that, in its turn, creates prerequisites for increase of weld ductility. Therefore, the authors of this work studied addition of rare-earth element fluorides to the flux component of flux-cored wire for welding VT22 titanium alloy.

**Welding and heat treatment of VT22 alloy with filler wire containing rare-earth elements.** Welding was performed on plates from VT22 alloy 8 mm thick, in three passes with 90° edge preparation (Table 2). Welding was conducted with application of an external transverse alternating magnetic field (20 Hz frequency, 4 mT value of magnetic inductance) for moving the arc column and weld pool, respectively, across the weld. Experimental flux-cored wire PPT-22 of 2.9 mm diameter was used as filler material. Flux of $CaF_2$–$SrF_2$–$BaF_2$–$LaF_3$ system was added to the flux filler of the wire.

Results of mechanical testing of welded joint (Table 3) showed that ultimate strength of weld metal with $LaF_3$ participation is lower than without it. However, impact toughness of welded joint with $LaF_3$, is 30 % higher that can be due to fine-grained structure of weld metal. Note that all the tensile samples failed not in the weld, but outside it, in the HAZ.

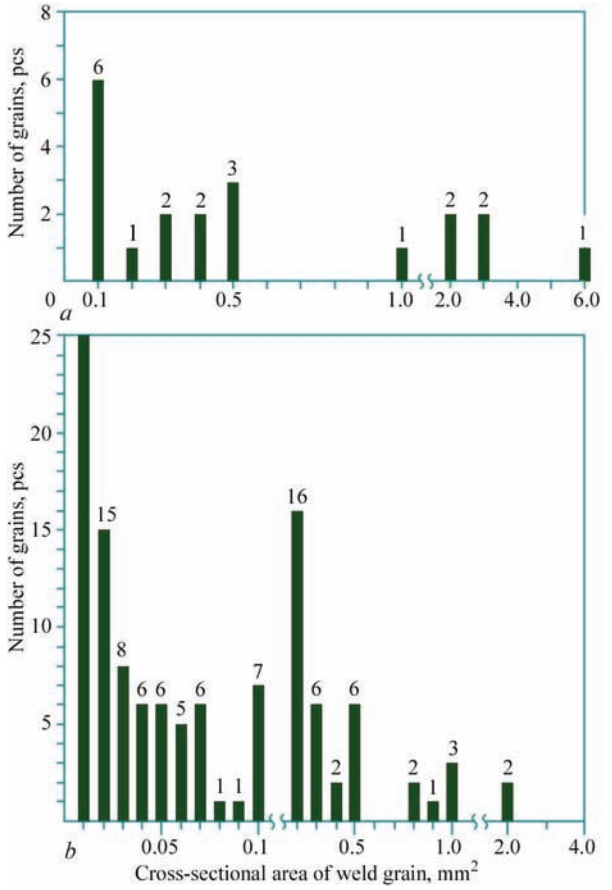


**Figure 3.** Histograms of distribution of the number of grains in welds of VT22 alloy, depending on their cross-sectional area: *a* — AAW without flux; *b* — AAW over $YF_3$ flux

Welded joints of VT22 titanium alloy are subjected to heat treatment (HT) to improve their mechanical properties. HT of titanium alloys is based mainly on polymorphous $\alpha \leftrightarrow \beta$ transformation. As a result of HT, the structure is stabilized, ductility and impact toughness of welds are considerably increased. At the same time, inner stresses arising during welding become lower.

In VT22 alloy with a significant content of β-phase, not only recrystallization processes occur, but phase composition also changes essentially at HT. This

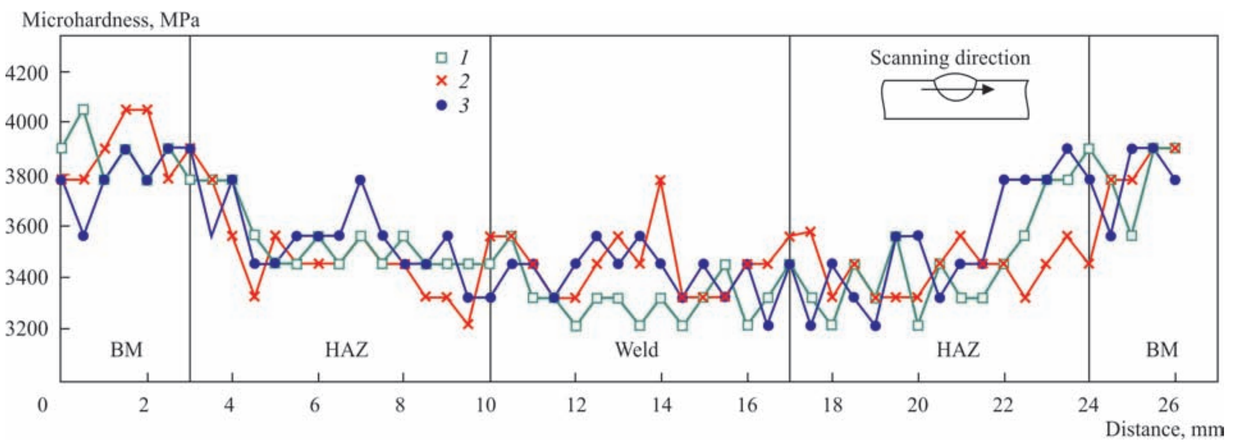


**Figure 4.** Microhardness of welded joints made by AAW without flux (*1*), over $YF_3$ flux (*2*) and over $LaF_3$ flux (*3*)

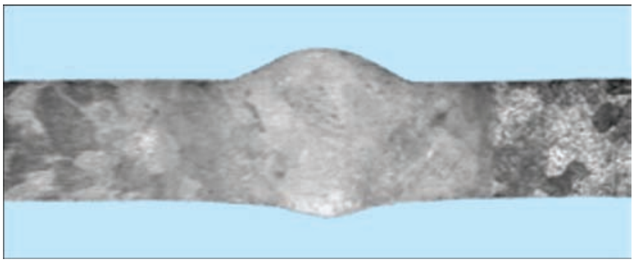

**Figure 5.** Macrosection of welded joint produced with flux-cored wire PPT-22 after two-step HT

greatly influences the mechanical properties. Changes in phase composition are controlled by cooling rates, as well as different steplike heating cycles.

At selection of HT mode, recrystallization temperature affecting the nature of phase transformations should be taken into account. Proceeding from analysis of published data [7, 8] quite simple technological process was selected for HT of welded joints made with application of flux-cored filler wire: soaking in the furnace at the temperature of 750 °C for 1 h, cooling with the furnace.

Investigation of weld metal macrostructure after annealing showed that annealing promoted formation of a homogeneous and uniform structure of the metal by weld height (Figure 5).

Analysis of obtained results of mechanical testing of samples shows positive summary influence of HT at addition of $LaF_3$ to the flux filler. As a result, at a slight decrease of strength (by 10 %), compared to samples without addition of rare-earth elements, impact toughness of the joint with $LaF_3$ is 2 times higher than that without its addition, and 35 % higher than base metal values (Table 4).

Investigation results show that addition of rare-earth elements to the flux component of flux-cored wire for welding VT22 titanium alloy influences the structural features of weld formation, namely, increase of the number of fine grains. It is shown that HT of welded joints of VT22 alloy, made by multipass welding with experimental filler wire PPT-22, promoted 2.5 times increase of impact toughness of the joints. Addition of $LaF_3$ to the wire allowed achieving an increase of impact toughness by 2 more times (up to 30.6 J/cm$^2$) that is higher than base metal values.

**Table 4.** Results of mechanical testing of base metal and welded joint after HT

| Test location | $\sigma_t$, MPa | *KCV*, J/cm$^2$ |
|---|---|---|
| Base metal | 1057.5* | 19.6 |
| Welded joint with $LaF_3$ | 955.4 | 30.6 |
| Welded joint without $LaF_3$ [5] | 1121.6 | 14.8 |

*The paper gives the results of testing three samples.


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