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APPLICATION OF TITANIUM ALLOYS WITH SUBMICROCRYSTALLINE STRUCTURE FOR RECONDITIONING OF GTE ROTOR PARTS

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Influence of structural condition of filler materials on the structure and properties of welds in welded joints of high-temperature titanium alloy VT8 is considered for the case of repair of aircraft engine parts. It is established that application of filler materials with submicrocrystalline structure allows ensuring an increase of the level of the joint mechanical properties.

Keywords: *argon-arc welding, titanium alloy VT8, filler materials, repair of aircraft engines, submicrocrystalline structure, weld metal, pores, mechanical properties*

Application of welding in manufacturing and repair of products from complex-alloyed titanium alloys is related to a whole number of problems. The most complex of them is welding of two-phase titanium alloys used in gas-turbine engines (GTE), as they are applied in different structural states, ensuring the required level of mechanical and service properties of material [1]. Weldability problems are related to a change of the structure of weld and HAZ metal, as well as formation of defects of weld structure (porosity, nonmetallic inclusions, chemical and structural inhomogeneity). One of the main defects is weld porosity responsible for up to 56 % of the general number of defects [2]. Weld properties and appearance of such defects as pores, nonmetallic inclusions, chemical and structural inhomogeneity in its structure directly depend on the composition and quality of filler materials. Issues related to filler material quality have gained special importance over the recent years, as complex-alloyed high-temperature titanium alloys are applied for thin-walled parts (blades, blisks, etc.) operating at the limit of material strength margin. Therefore, presence of microdefects in filler materials can lead to a complete loss of performance of the reconditioned parts. Several works describe the methods to reduce the number of defects in filler materials [3, 4]. The proposed solutions, however, pertain to surface defects and do not solve the problems of volume structural state of the fillers.

Thus, in welding of critical parts from high-temperature titanium alloys applied for GTE rotor parts, it is necessary for filler materials to provide a stable high quality of the weld. The present work deals with the influence of structural state of filler materials on the structure and properties of welds in welded joints of high-temperature titanium alloys.

Materials and investigation procedure. Welded joints of two-phase high-temperature titanium alloy VT8 were selected as an object of investigations. This alloy is used for monowheels (blisks) of high-pressure compressor (HPC) of D27 turbofan. 2 mm plates from VT8 alloy were welded by argon-arc welding by 1.8 mm nonconsumable tungsten electron in the following modes: I_w = 180 A, U_w = 10 V. VD302 power source, U6872-5306 chamber with controllable atmosphere (argon), filler materials of standard compositions (VT2 alloy wire and VT8 alloy rod) were used. 2 mm rods of the same composition, but with submicrocrystalline (SMC) structure were used as experimental filler materials. Blanks for rods with SMC structure were produced at realization of intensive plastic deformation by the method of helical extrusion with simultaneous application of normal and tangential stresses at temperatures of 400–800 °C [5, 6].

Chemical composition was studied by means of chemical analysis to GOST 19863.1-19863.13 and microanalysis in the JEOL scanning electron microscope JSM-T300. Microstructure was studied in optical microscope «Neophot-32» and transmission electron microscope JEM-100CXII at accelerating voltage of 100 kV, as well as in scanning electron microscopes JSM-T300 and REM-106I with energy dispersive

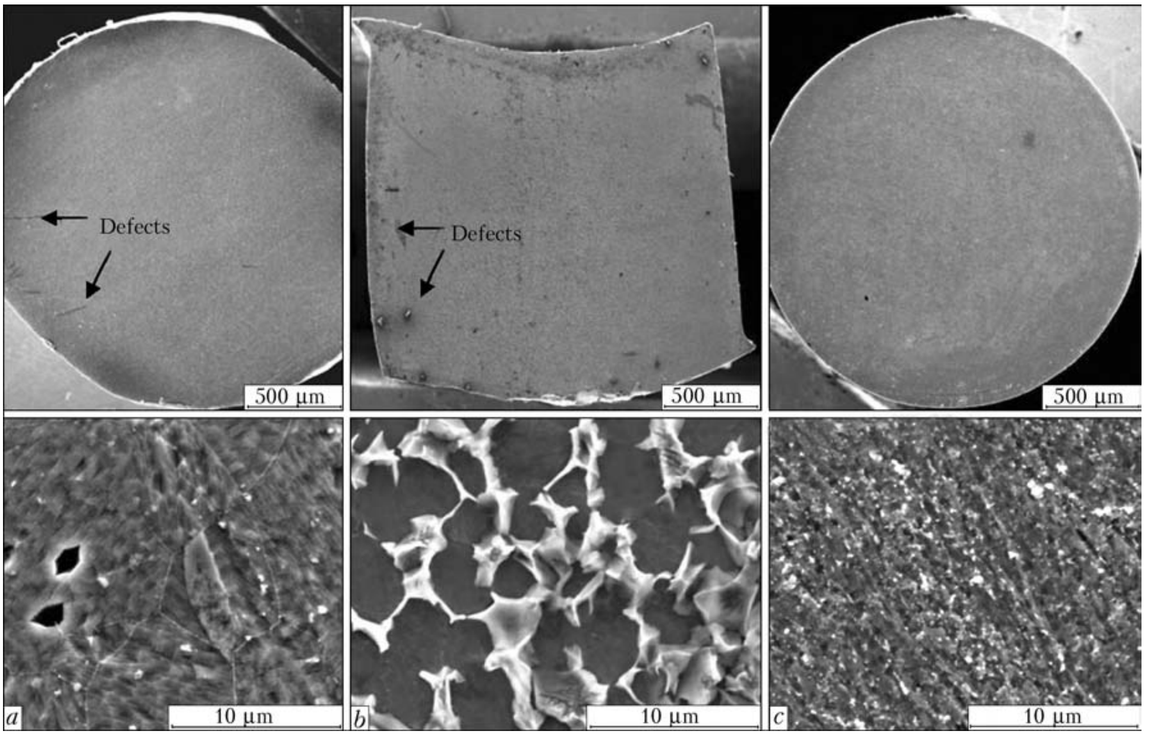

Figure 1. Macro- and microstructure of filler materials: *a* — VT2 alloy wire; *b* — VT8 alloy rod; *c* — VT2 alloy rod with SMC structure

analysis along a line and in a point. Mechanical properties were determined in the INSTRON tensile testing machine. Static strength and bend angle ψ of welded joints were determined according to GOST 6996–66 «Welded joints. Methods of determination of mechanical properties» and GOST 14019–2003 «Metallic materials. Method of bend testing», and pore quantity — by quantitative metallography methods [7]. At analysis of the surface of sample fracture in the weld, the number and size of pores per 1 mm^2 were recorded. Microhardness was studied in the BUEHLER microhardness meter MM7T (by the procedure to GOST 9450–76).

Investigation results and their analysis. As was noted above, the main causes for weld porosity are defects in the filler material structure. Analysis of the results of investigation of macro- and microstructure of standard filler materials revealed the presence of pores and discontinuities in the wire of VT2 alloy (Figure 1, *a*). These defects were technological, characteristic for wrought alloys.

The second drawback concerning the chemical and structural inhomogeneity of filler materials is characteristic for complex-alloyed titanium alloys (Figure 1, *b*). Investigations of standard filler materials applied in welding of VT8 alloy showed their chemical inhomogeneity (Figure 2).

Microanalysis of structural components demonstrated a significant difference in the content of the main alloying elements in α- and β-phases for an alloy of the following average composition, wt.%: Ti — base; 5.8 Al; 3.1 Mo; 0.3 Si; 0.5 Zr. In α-phase the content of α-stabilizing aluminium was equal to about 5.24 %, its minimum content in β-phase was within 2 % (Table 1). An inverse regularity was found in distribution of β-stabilizing elements, that is the most clearly manifested in molybdenum content (more than 10 times).

Presence of chemical inhomogeneity determined the difference in mechanical properties. Investigation of microhardness of structural components of VT8 alloy demonstrated that α-phase on average had microhardness of $3932 \cdot 10^6$, and β-phase — $2215 \cdot 10^6$ MPa. Difference in microhardness between α- and β-phases was more than 70 %. In welding and surfacing of thin-walled critical items of up to 1 mm thickness (blades, monowheels, etc.), such a difference in phase composition and properties in standard fillers can lead to a significant change in weld properties.

To eliminate the above defects, a new approach to formation of filler material structure was defined. It was proposed to apply filler materials with nano- or SMC structure. This, according to results of earlier research, will allow achieving a uniform distribution of alloying elements in the filler material volume.

Experimental material rods were produced by a specially developed technology, which was based on

Table 1. Alloying element content in structural components of VT8 alloy, wt.%*

Analysis section (phase)	Al	Mo	Zr	Fe	Si
001 (α-phase)	5.24	0.51	–	–	0.11
002 (β-phase)	4.08	3.55	0.80	1.08	0.28
003 (β-phase)	2.02	7.08	1.10	1.15	0.08

*Ti — base.

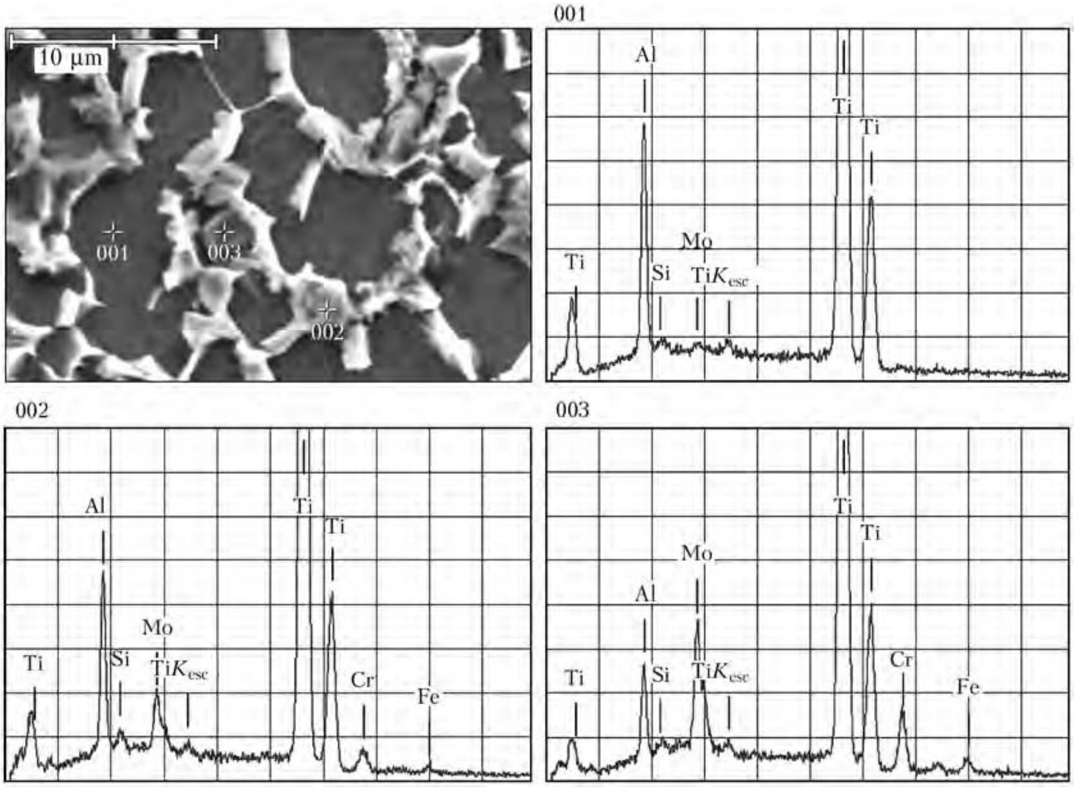

Figure 2. Energy-dispersion spectra in structural components of filler material from VT8 alloy

the method of helical extrusion [5, 6]. Application of intensive plastic deformation method for complex-alloyed titanium alloys ensured a more uniform distribution of alloying elements that is quite comprehensively described in [8, 9]. As a result, alloying elements were uniformly distributed through the entire alloy volume, and chemical and structural inhomogeneity in filler materials with SMC structure was practically absent. Filler materials with SMC structure did not have any pores, discontinuities or other defects, noted for standard alloys, that is readily seen on macro- and microsections (see Figure 1, *c*). Absence of the above defects, obviously, was the consequence of «healing» of pores under the impact of high pressures and higher temperature. A similar effect is used in treatment of cast titanium alloys in a gasostat [10, 11].

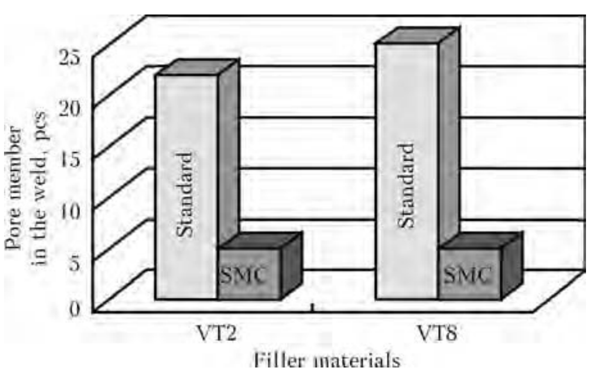

Figure 3. Number of pores on fracture surface of the weld in welded joints of VT8 alloy produced with application of standard and test filler materials with SMC structure

Comparative investigations of welded joints of plates from high-temperature titanium alloy VT8, produced with application of standard filler materials or those with SMC structure, showed that in the second case an increase of the level of welded joint mechanical properties was observed (Table 2).

As follows from analysis of the presented data, the level of mechanical properties of welded joints, produced with application of SMC filler materials, increased in terms of both strength and ductility, compared to standard fillers. Application of fillers with SMC structure allowed improving the stability of welded joint properties. Average value of ultimate strength for welded joints with application of fillers with SMC structure, made of VT2 titanium, was equal to 948 MPa, and for standard fillers it was not higher than 890 MPa. Difference in the value of ultimate strength between the joints made with fillers with SMC structure and standard fillers from VT8 alloy was equal to 65 MPa.

Table 2. Mechanical properties of welded joints on plates from VT8 titanium alloy produced using various filler materials

Filler	Fracture site	σ_t, MPa	$\sigma_{0.2}$, MPa	δ, %	ψ, %
VT2	Weld	888.0	476.7	5.9	61.5
VT2 (SMC)	Same	948.3	520.0	6.5	72.0
VT8	HAZ, weld	1083.2	656.3	4.7	23.0
VT8 (SMC)	HAZ	1148.3	705.7	5.4	31.3

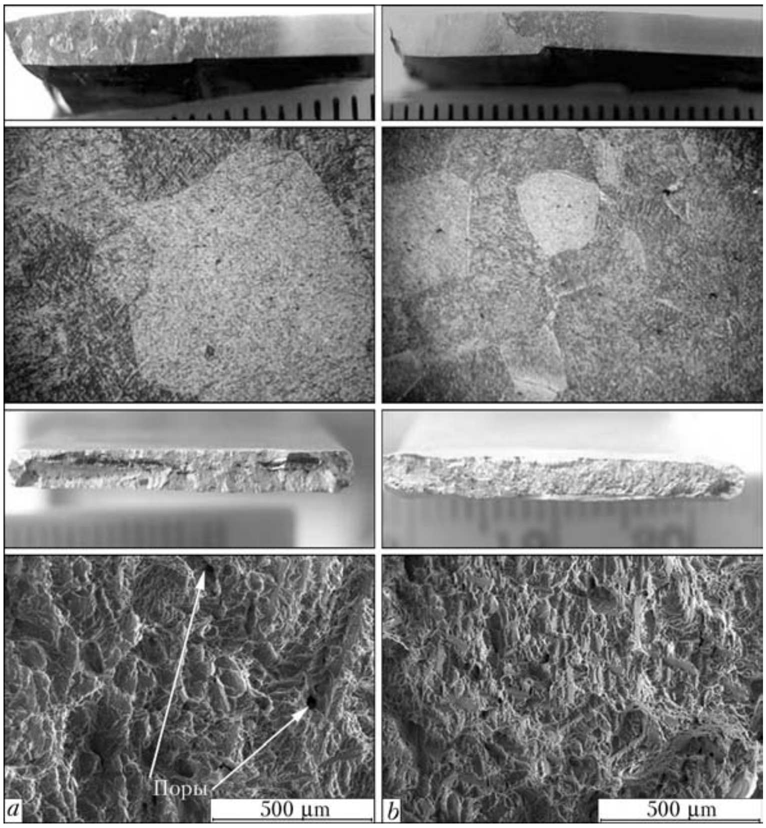

Figure 4. Characteristic view of fracture surface and microstructure of weld metal of welded joints on VT8 alloy at application of standard (*a*) and test filler materials with SMC structure from VT2 alloy (*b*)

A similar tendency was established also for ductility indices. For welds made with application of fillers with SMC structure, average value of bend angle was by 14.58 % for VT2 filler and by 26.4 % for VT8 filler higher than for welds made with fillers with a standard structure.

An important aspect is improvement of stability of test joint properties. So, maximum scatter of properties was found for joints produced with application of standard fillers. As to strength indices, scatter of properties was equal to: for σ_t — about 15, for σ_y — about 19 %. Here, the sample failed in the weld, and, therefore, fracture was caused by structural defects. For welded joints made with fillers with SMC structure, scatter of strength properties did not exceed 3 %, and for bend angle — 12 %. For standard fillers the difference in bend angle of welded joints was about 33 %. The established regularity is characteristic also for relative elongation. On the whole, welded joints, obtained with application of fillers with SCM structure, had higher values of mechanical properties: ultimate strength — by 6.32 and 5.66 %, yield point — by 8.14 and 7 %, relative elongation by 8 and 15 %, bend angle — by 14.5 and 26.4 % for unalloyed and alloyed fillers, respectively.

Higher and more stable properties of welded joints, produced with application of fillers with SMC structure, can be attributed to the fact that welded joint structure contains a much smaller number of defects. This was confirmed by the results of investigation of weld defects. Pores on weld fracture surface of more than 20 μm size were regarded as defects. Investigation results are given in Figure 3.

As follows from analysis of the presented data, in welded joints made with fillers with SMC structure pore number is 4–5 times smaller than that for joints produced by standard technology. Reduction of the number of defects in the weld of test joints led to an increase of weld metal fracture toughness, as follows from the appearance of welded joint fracture surface (Figure 4).

Pores of 20 to 80 μm size were found on fracture surface of welded joint produced by the standard technology. Mode of sample fracture leads to the conclusion about the connection between the found pores and formation of initial cracks and their subsequent propagation. In joints made with application of alloys with SMC structure, pores were practically absent, that, apparently, also ensured a higher level of mechanical properties of these joints compared to standards ones.

CONCLUSION

Application of filler materials with SMC structure instead of standard fillers allows:

• eliminating pores and discontinuities in filler material structure as a result of «healing» of the latter under the impact of volume deformation at elevated temperature by the principle similar to gasostatic treatment;

• lowering the chemical and structural inhomogeneity, characteristic for fillers from two-phase titanium alloys;

• increasing the energy intensity of fracture of welded joints on high-temperature titanium alloys due to reduction of the number of defects in the weld structure;

• increasing the values of mechanical properties of welded joints from VT8 alloy, compared to joints made with application of standard fillers.

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EFFECT OF HIGH-TEMPERATURE THERMAL CYCLING ON DEPOSITED METAL OF THE TYPE OF HEAT-RESISTANT DIE STEELS

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The effect of high-temperature cyclic loads on thermal stability, structure and microscopic chemical heterogeneity of deposited metal of the type of heat-resistant die steels was investigated. It was shown that, despite the fact that no diffusion of main alloying elements was detected during the tests, structure of the deposited metal experienced changes leading to its weakening.

Keywords: *arc cladding, flux-cored wire, deposited metal, forming rolls, dies, thermal cycling, thermal stability, structure*

One of the main types of wear of working surfaces of forming rolls, dies and other tools used for hot deformation of metals is thermal fatigue, i.e. formation of a network of fire cracks caused by high-temperature cyclic loads [1–4]. The thermal fatigue cracks form on the surfaces of parts after some (relatively small) quantity of thermal cycles. They result from the effect of cyclic thermal stresses induced by constraint changes in size of isolated regions of a part in periodic fluctuations of temperatures [5–8].

A combination of cyclic temperatures and elasto-plastic deformations is a characteristic feature of anisothermic cyclic fatigue. The type of anisothermic cyclic fracture, at which the maximal temperature of a thermal cycle corresponds to compression in a cycle of elasto-plastic deformation, was called the thermal fatigue [5, 6]. The quantity of the heating–cooling cycles to formation of cracks usually serves as a characteristic of resistance of materials to thermal fatigue [2, 3].

Depending on the test procedure that meets service conditions of parts to this or other extent, the quantity of thermal cycles leading to formation of the thermal fatigue cracks for the majority of materials does not exceed several hundreds or thousands of the heating–cooling cycles [2–3].

In addition to thermal stresses, when investigating thermal stability of the deposited metal it is necessary

Table 1. Chemical composition and hardness of deposited metal

Flux-cored wire grade	Content of elements, wt.%							Hardness *HRC*
	C	Mn	Si	Cr	W	Mo	V	
PP-Np-30Kh4V2M2FS	0.35	0.72	1.1	3.97	2.52	1.88	0.44	50
PP-Np-35V9Kh3GSF	0.34	0.6	1.0	3.0	9.3	–	0.71	54