INCREASING WEAR RESISTANCE OF TITANIUM BY ARGON ARC OVERLAYING

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Results of the comprehensive investigations aimed at development of a fundamentally new overlaying consumable for deposition of wear-resistant layers on the surface of titanium alloys, i.e. titanium flux-cored filler wire, are given. The process was developed for overlaying by using the argon arc controlled by the external transverse alternating magnetic field. It is shown that the deposited metal provides a 10 times increase in tribotechnical surface properties of titanium VT1-1.

Keywords: *arc overlaying, titanium flux-cored wire, argon, wear resistance of deposited layer, controlled magnetic field*

Titanium alloys are finding an increasingly wider application in power engineering, motor car construction, aerospace engineering, aircraft engineering and other industries. However, independently of the type and system of alloying, titanium alloys are susceptible to contact seizure in friction and, consequently, to considerable wear and mechanical damage of contact surfaces. Susceptibility to frictional seizure is an important drawback of titanium alloys, which makes it difficult and in a number of cases impossible to use them in friction units of machines and mechanisms. Tribotechnical properties of parts of titanium alloys can be improved by using the same friction surface treatment technologies as those used for other metals: thermochemical treatment, electroplating, spraying, laser and electric-spark surface alloying, etc. However, the efficiency of these technologies for titanium alloys is low, as a rule, and does not meet the necessary requirements. For instance, thickness of a layer in thermochemical treatment does not exceed 100 μm, electroplated coatings fail rapidly, thickness of the plasma-deposited layer is not in excess of 0.35 μm, and depth of the molten zone in laser and electric-spark surface alloying is no more than 120 μm. Essential drawbacks of such coatings are a limited thickness of the deposited layer and its cracking. The most promising process for this purpose is overlaying by the arc method using the specially developed composite materials and alloys that contain carbides [1].

The authors of study [2] developed a titanium-base wear-resistant overlaying consumable that is dispersion-strengthened by carbides. The alloy suggested provides high tribotechnical properties of the deposited surface in overlaying on titanium parts. However, low deformability of this alloy does not allow making a consumable from it in the form of a filler wire. The absence of such materials hampers considerably development of a reliable overlaying process, which could make it possible to change surface properties of the titanium parts by the argon-arc method in the automatic mode.

The purpose of this study was to develop the fundamentally new type of an overlaying consumable for titanium, which would provide a deposited layer on the surface of the titanium parts with the required level of tribotechnical properties, as well as to elaborate the process for depositing it by using the argon arc.

The new overlaying consumable was developed on a base of titanium flux-cored wire, which consists of a sheath of commercial titanium of the VT1-00 grade with a core located inside it [3]. The core contains a composite powder produced as a result of interaction between nanosized non-stoichiometric silicon carbide in the form of its carbon solid solution and titanium.

Synthesis of the solid solution of carbon in silicon carbide is provided in the dispersed silicon–thermally expanded graphite (TEG) system, this leading to development of self-propagating high-temperature synthesis (SHS) of non-stoichiometric silicon carbide with a decreased value of the lattice parameter [4]. A distinctive feature of the suggested process is that owing to structural peculiarities of TEG its mechanical mixing with dispersed silicon results in formation of conglomerates of particles with a honeycomb-like structure. This structural state of the charge allowed the SHS method to be modified by initiating it in microvolumes and intensifying the gas-transport reactions. Performance of certain operations on preparation of TEG and temperature treatment of the charge creates conditions for development of «glow» SHS of silicon carbide. Such non-equilibrium synthesis conditions provide a characteristic structural state formed as a result of violation of stoichiometry, this leading to formation of a nano-composite structure of the particles, similar to that of the solid solution of carbon in silicon carbide [4].

Examinations of structure of these particles characterised by a decreased value of the lattice parameter show that the «glow» SHS process provides formation

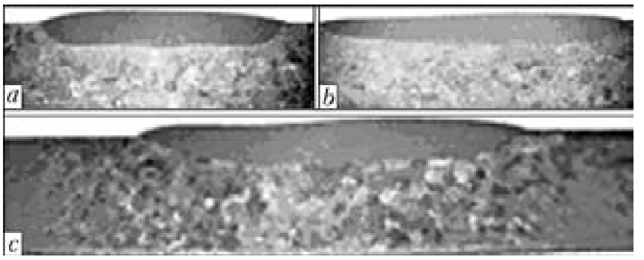

Figure 1. Effect of values of magnetic induction on width of deposited layers: *a* — B = 6.2 (S1); *b* — 7 (S2); *c* — 7.5 mT (S3)

of the states that are caused by the planar carbon defects present in a structure. The concentration of these defects is not in excess of 1 at.%, this leading to a formula content of silicon carbide equal to $Si_{0.993}C_{1.007}$ [5].

The exothermic reaction occurring in a mixture of the synthesised silicon carbide powder (solid solution of carbon in silicon carbide) and electrolysis titanium powder leads to formation of new phases, such as titanium carbonitride and silicide (TiC_xN_y and Ti_xSi_y). Variations in weight proportions of the charge components allows achieving different formula states of titanium carbonitride and silicide, which is a result of non-equilibrium of the process and exothermicity of the reaction between silicon carbide and titanium. The proportion of the components established by optimising the charge composition is 25SiC–75Ti. This resulted in formation of the finely dispersed composite powder containing titanium carbonitride $TiC_{0.4}N_{0.6}$ and titanium silicide Ti_5Si_3 intended for use as a flux-cored wire core.

The flux component containing fluorides of alkali-earth metals was added to the charge of the core to prevent porosity in overlaying and increase density of the deposited metal.

Noteworthy is the expediency of performing overlaying by the argon arc method, which is the most extensively used and versatile method for automatic welding of titanium. The main difference of the overlaying process from the welding one is that in overlaying it is necessary to ensure the minimal depth of penetration of the base metal. This requirement is difficult to meet by using the free-burning argon arc, as it causes uncontrollable deep penetration of the base metal at the centre of the arc column. As a result, the deposited metal mixes with the base one, thus leading to anisotropy of properties of the deposited layer both through the height and along the length. Moreover, changing the width of the deposited layer by this method in one pass is a real problem.

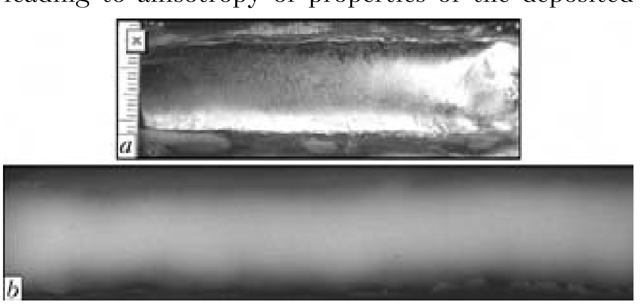

Figure 2. Appearance (*a*) and X-ray photograph (*b*) of deposited layer

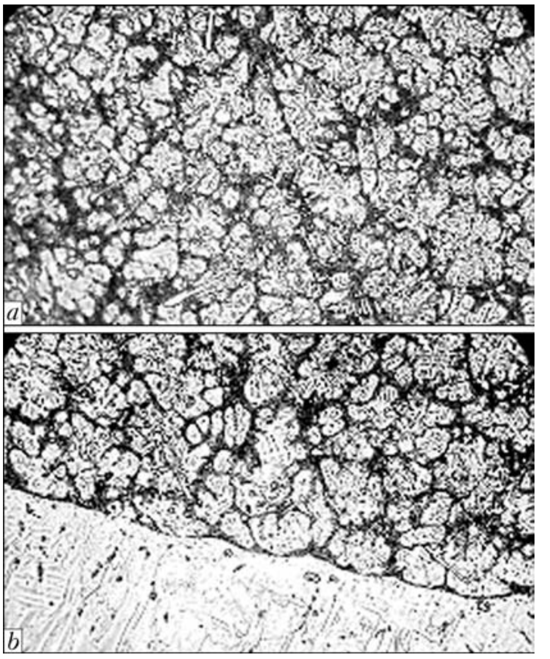

Figure 3. Microstructure (×200) of central part of deposited metal layer (*a*) and fusion zone (*b*)

The external transverse magnetic field that allows controlling the process of formation of the deposited layer was used to regulate the width of this layer and, at the same time, decrease the depth of penetration of the base metal [6].

The investigations conducted resulted in the development of the process for manufacture of the 3 mm diameter flux-cored filler wire, as well as in the determination of the main parameters of the magnetic field providing the deposited layer with the required properties in one pass. For instance, a change of 6.2–7.5 MT in the value of magnetic induction B at frequency f = 4 Hz provides the deposited layer up to 20 mm wide at a penetration depth of no more than 2 mm (Figure 1).

The deposited metal layer features a satisfactory formation (Figure 2, *a*) and is free of pores (Figure 2, *b*). Microstructural examinations of the deposited metal layers revealed the presence of a uniform dendritic structure (Figure 3). Characteristic structural peculiarities observed in the central part of the deposited metal persist also in the immediate proximity to the fusion zone, this being indicative of stability of functional properties in the entire volume of the deposited metal layer.

Examinations of phase composition of the deposited metal layer by X-ray diffraction analysis showed that it consists of three phases: α-Ti, hypostoichiometric titanium carbide TiC_x ($x \approx 0.5$), in which part of the carbon atoms are replaced by the nitrogen atoms, and a high-temperature phase of titanium silicide Ti_5Si_3 (Figure 4).

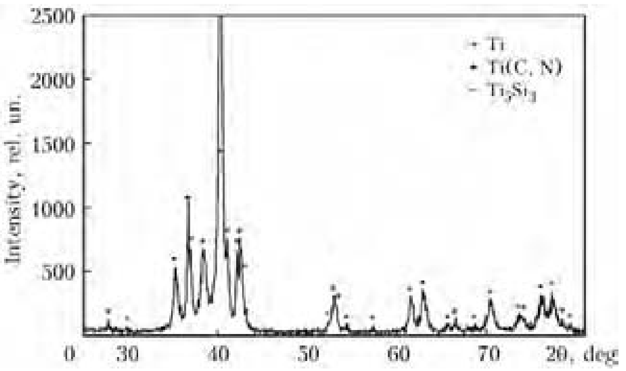

Figure 4. Typical X-ray pattern of metal of the layer deposited on the VT1-1 substrate

Evaluation of properties of the deposited metal layers showed that the values of microhardness ($HV0.2$) amount to 14–15 GPa, and those of hardness ($HV30$) – to 9.0–9.5 GPa.

Tribological tests were carried out on the deposited metal specimens (S1, S2, S3) made under different process conditions (see Figure 1). To compare, tribological properties of the VT1-1 substrate were investigated as well. Wear resistance was evaluated from the loss of weight of a specimen on a friction path of 1 km. The test results are presented in Figure 5.

Comparison of the intensity of wear (weight loss) of the deposited specimens with that of the substrate specimen showed that the deposited specimens are superior by almost an order of magnitude to the substrate in wear resistance under the 2 and 4 kg loads. Under a load of 6 kg the value of wear resistance of the deposited specimens decreases, but compared to that of the substrate it is 2 to 6 times higher. Wear of the mating body (steel 45, HRC = 45–48) decreases under the 2 and 4 kg loads from 5 to 7 times, whereas under the 6 kg load it decreases by a factor of 2.6 to 2.8.

Therefore, the investigations conducted proved the possibility of a 10 times increase in tribotechnical properties of surfaces of the plates of titanium alloy VT1-1.

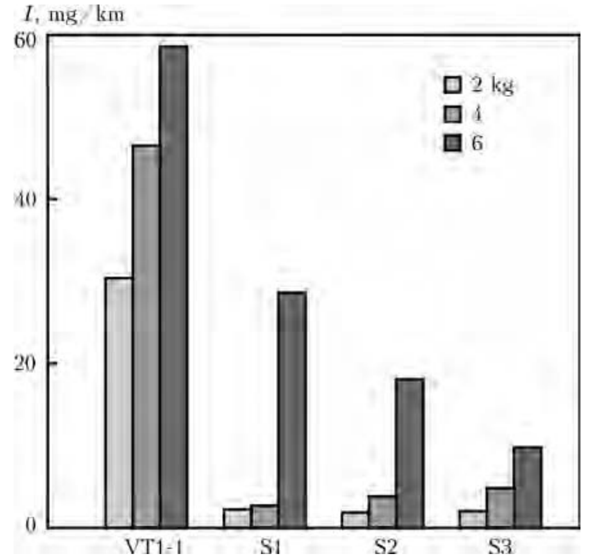

Figure 5. Intensity I of wear of specimens versus load

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