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Deposition of a titanium coating on a steel base by contact welding and study of the resulting layered system structure

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Abstract. The paper describes a method for the deposition of a titanium coating on the base of steel grade Cr12MoV for the subsequent modification of the layered system. The resistance welding parameters required for the formation of the "steel – titanium" structure with an increased hardness of 300–800 HV were established.

1. Introduction

To increase the service life of metal parts operating under the conditions of increased wear (in friction pairs) or in harsh environment, the working parts are coated with protective films or coatings by various methods [1-3]. To protect the working parts of tools from oxidation and to increase the reliability of products at high temperatures, materials with high heat resistance are deposited on the surface: refractory materials, highly alloyed chromium-nickel alloys, cermets in the form of oxides and nitrides. For the application of functional coatings, various methods are used that depend on the deposited coating type. Physical vapor deposition (PVD method for the formation of nitride coatings), gas-flame and plasma deposition of the coatings (APS method for the deposition of oxides and refractory materials), electrospark modification (fusion) and alloying of the surface are widespread. In almost all cases, after the coating is deposited on the product surface, there is a problem in achieving a strong connection of dissimilar metals. This occurs when applying a titanium layer (coating) on a steel base in the form of a foil or a thin sheet.

To fix a functional metal coating of large thickness (about 1 mm or more) on the base of the product, welding and surfacing methods are used. In particular, welding through thin interlayers is applied to form an integral connection between titanium and steel. Vanadium and eutectic Cu-V copper alloys are used for the intermediate layer [3,4]. The metal for these layers is selected so that it is suitable for the formation of a strong connection with both metals of the system. In the zone of the "Fe – Ti" welded joint obtained by welding (TIG method) during the formation of the intermetallic "Fe – Ti" and "Fe – V" phases, the hardness can reach 1100 HV and the hardness of the zone affected by the welding heat is about 270–400 HV. However, in the case of a high temperature (HT) process, an intermetallic phase with a hardness of 10 to 23 GPa can be formed.

The method of diffusion and laser welding of low-carbon steel with titanium alloys involves the use of niobium as an intermediate layer [5,6]. It is known that diffusion welding of Ti-6Al-4V titanium alloy and AISI 316L steel is carried out at a temperature of 900±50 °C, a duration of not more than 90 min and a pressure of at least 30 MPa. The strength of this compound reaches 500 MPa with a microhardness of about 100–200 HV.

The resistance welding between the chrome steel with a thickness of $h = 3.5$ mm (carbon – 0.9–1.0 wt.%, chromium – 17–19 wt.%) and the commercially pure titanium with a thickness of $h = 0.5$ mm is performed at a pulse duration of 500 ms and an operating current of not less than 1 kA [7]. The



resulting weld joint has an average hardness of about 470–490 HV. Thus, resistance welding might not require the intermediate layers to ensure a strong connection with the presence of hard layers.

Therefore, the use of resistance welding for the formation of an integral connection between tool steel and commercially pure titanium is studied in this work.

2. Methodology

The experimental samples were made in the form of disks of Cr12MoV steel with a diameter of 14 mm and a thickness of 3.5 mm. The coating was obtained from a 0.2 mm thick sheet of a titanium alloy of the TA2 grade (VT1-00 analogue).

After preparing the surfaces to be welded (machining and cleaning), resistance welding was performed with a variable value of the consumed voltage U and pulse duration t . As a result, a layered "Cr12MoV steel + Ti coating" structure was obtained, the total height of which was 3.65–3.70 mm.

The contact welding of titanium with steel was carried out in a laboratory setup, which included a laboratory autotransformer 1 and a resistance welding machine 2 (Figure 1). The voltage of the laboratory autotransformer was set in the range from 160 to 175 V. The pulse duration was adjusted at the resistance welding machine in the range of 250–1000 ms. Two weld points without overlap were marked on one of the samples (at a distance of 4–5 mm from one another). The diameter of the contact area of the lower and upper electrodes was 6 mm.

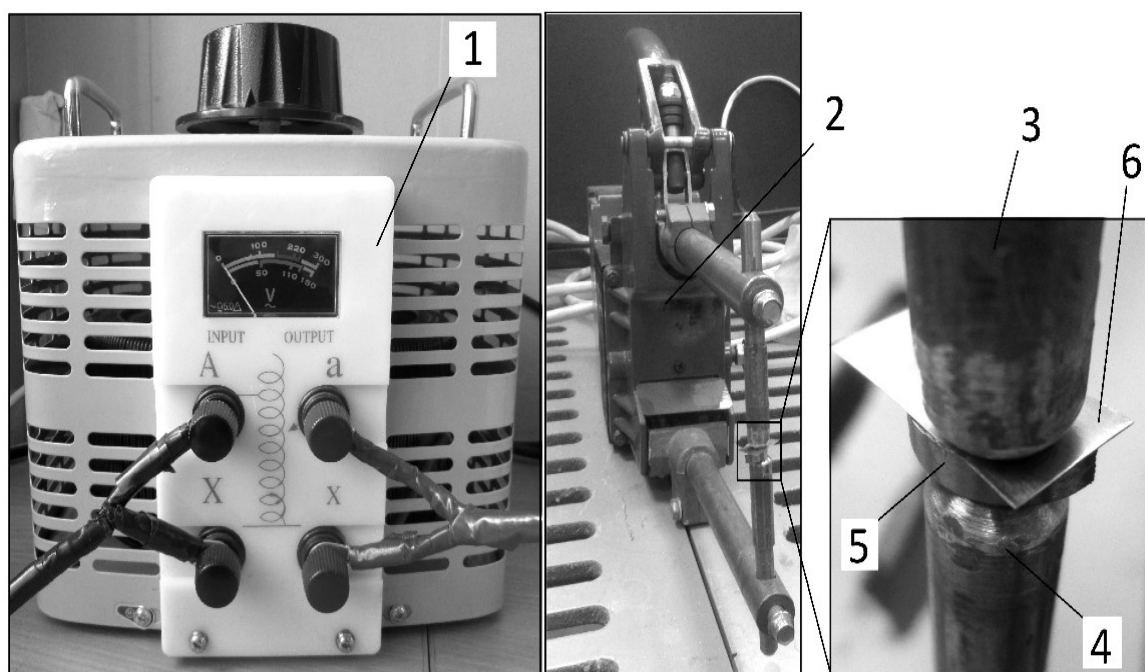


Figure 1. A laboratory setup containing a laboratory autotransformer 1 and a resistance welding machine 2, and an arrangement of working electrodes 3,4 and welded parts 5,6.

The microstructure and quality of the welded joint of the resulting system were analyzed using optical microscopy. The prepared microsection samples of the composite structure were studied in the active spot of resistance welding.

To analyze the stress state, the microhardness was measured by the Vickers method (HV) at a load of 50–100 gf.

3. Results

At the voltage $U = 160$ V and pulse duration $t = 250$ ms, a high-quality and strong joint could not be formed. The microscopy results showed that titanium had no permanent deformation. No significant thermal effect on the steel base was observed as well (Figure 2a). When analyzing the cross section, it was found that the difference in hardness between steel and titanium was quite high and it had no smooth increase from titanium to steel. This characterized a reduced diffusion rate between these metals.

Analysis of the microstructure of the sample obtained at $U = 160$ V and the welding pulse duration $t = 1000$ ms proved that there occurred the formation of intermetallic compounds 1 (Figure 2c). Their presence usually causes a decrease in bond strength and increased fragility.

An increase in voltage to $U = 175$ V at $t = 250$ ms led to a significant deformation of the titanium layer and a decrease in thickness by half (Figure 2d). With the given treatment parameters, pores 2 were also formed in the fusion region. The hardness of this joint gradually increased from titanium to steel, which characterized the absence of intermetallics and good alloying of titanium with steel.

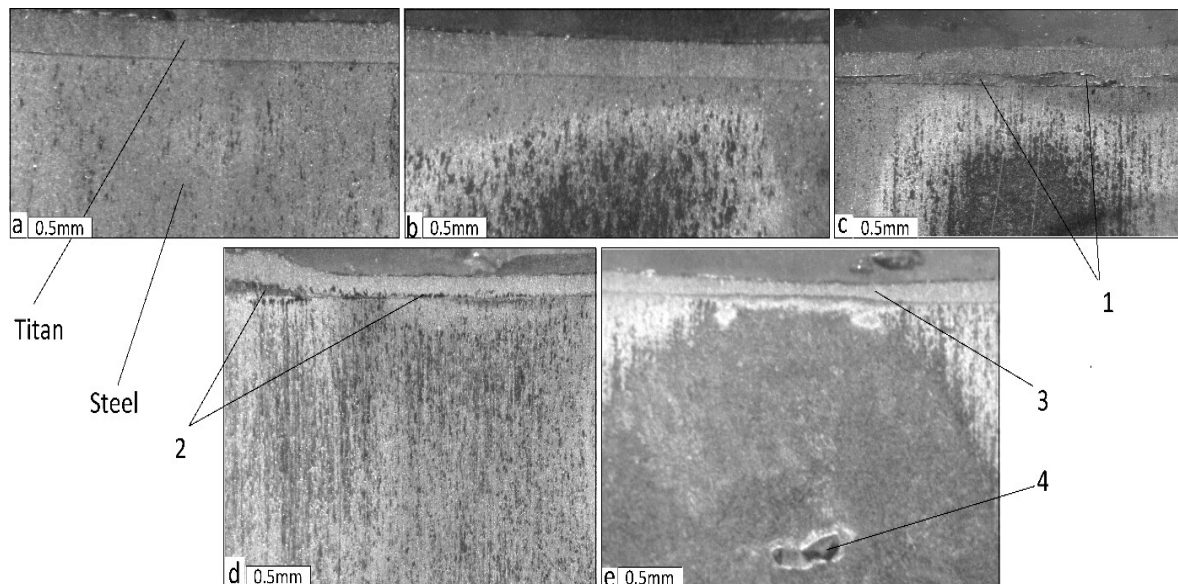


Figure 2. Cross section of a welded joint and its layered structure consisting of a base and a coating: *a* – $U = 160$ V, $t = 250$ ms; *b* – $U = 160$ V, $t = 500$ ms; *c* – $U = 160$ V, $t = 1000$ ms; *d* – $U = 175$ V, $t = 250$ ms; *e* – $U = 175$ V, $t = 500$ ms.

An increase in the pulse duration $t = 500$ ms at a voltage of 175 V led to excessive heat exposure and the formation of voids 4 in the central part of the steel base (Figure 2e).

The use of the reduced voltage $U = 160$ V at $t = 500$ ms led to the formation of a uniform joint. A low degree of deformation in titanium under the compression of the electrodes was practically not observed with a moderate thermal effect of the current pulse Figure 2b). The indicated pulse duration was sufficient for the formation of a strong and uniform joint (without defects in the form of pores) and the formation of intermetallic compounds in the joint region.

According to a typical hardness chart for a sample of a welded joint with a uniform structure, it can be seen that there was a gradual increase in hardness in the weld zone from titanium to steel (Figure 3). During welding, diffusion proceeded without the formation of brittle intermetallic compounds. Hardness equaled 400–450 HV in the fusion zone. Thus, it was concluded that high strength was obtained for the "Cr12MoV steel – titanium TA2 coating" system.

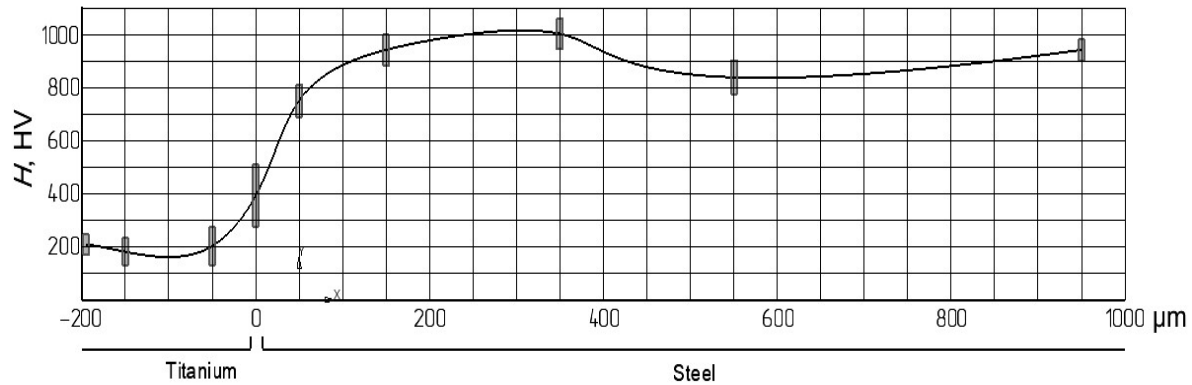


Figure 3. Distribution of microhardness HV over the cross section of a defect-free "steel – titanium" structure.

4. Conclusions

Thus, when welding dissimilar materials, in particular steel and titanium, energy-efficient contact welding modes were determined in order to form a strong joint of the layered "Cr12MoV steel + Ti-coating" system. The resulting structure can be further thermally modified to increase the wear resistance of the working surface, *e.g.* that of a metalworking tool.

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