Structure of "Chromium steel-base – Ti-coating" and its production by the contact welding

I Egorov, A Shchelkunov, A Fomin, I Rodionov
1 Yuri Gagarin State Technical University of Saratov, Saratov 410054, Russia

Abstract. This paper describes an innovative approach for the production of a weld joint between a steel base and a titanium plate using a method of contact welding. As a result, a "Chromium steel-base – Ti-coating" structure with high strength and hardness about 450 HV was formed. The possibility of further machining, including drilling, turning and grinding for the production of rectangular plates was shown.

1. Introduction

To improve the performance characteristics of metal products, their surface is treated by various methods, including the application of functional films and coatings [1,2]. To improve the corrosion resistance and operational reliability of products that are used at high temperatures, heat resistant materials are deposited on their surface, e.g. high-alloyed chromium-nickel steels, cermet compounds (nitrides, oxides) and some pure refractory metals. Functional coatings can be applied by various gas-thermal methods (physical vapour deposition (PVD), high velocity oxygen fuel (HVOF) and plasma spraying [1], electrospark alloying and deposition [2]), but there are difficulties in combining non-homogeneous metals, in particular a steel base and a titanium coating.

One of the methods for obtaining functional metal layers is welding and surfacing. To increase the strength of the welded joint between steel and titanium, thin vanadium interlayers are used [3]. Vanadium, which is more refractory compared to titanium and iron, provides a higher strength of the welded joint. In electric arc welding, e.g. TIG, intermetallic phases with high hardness (~1112 HV0.01) appear in the transition region of the interaction of dissimilar materials (Fe-Ti, Fe-V). The average hardness of the welding area is 275–400 HV. To improve the quality of Fe-Ti compound, eutectic Cu-V alloys are also used [4]. The formed Fe2Ti intermetallic phase and FeTi+β-Ti mixtures have a high hardness from 10 to 23 GPa.

The problem of welding low-carbon steel and titanium is also solved in the case of friction welding [5]. In the tensile test, the fracture of welded joint samples occurs over steel, rather than in the area of welding. In the case of diffusion and laser welding, Nb [6,7] is used as the interlayer. For example, diffusion welding of AISI316L stainless steel and Ti-6Al-4V titanium alloy is conducted at a temperature of about 900±50 °C for the time not exceeding 90 min at the pressure of 30 MPa. The welded joint strength reaches a maximum value of about 500 MPa, while the microhardness of the welded joint is 100–200 HV. In the case of welding TC4 titanium alloy to stainless steel SUS301L, the strength of the joint equals 370 MPa.

Therefore, in this paper, the possible formation of "Chromium steel-base – Ti-coating" structure by the method of contact welding is discussed.
2. Methodology
Experimental samples were made in the form of 0.5 mm thick titanium Grade 2 and 3.5 mm thick chromium steel plates (carbon – 0.9–1.0 wt.%, chromium – 17–19 wt.%). The layered "Steel – Ti" structure with a total thickness of 4–4.2 mm was obtained by contact welding (Figure 1a).

The working current was measured using current clamps (Figure 1b). Current strength in contact welding was 1.95±0.05 kA, and the diameter of the wire electrode was not less than 5 mm. In this work, the influence of pulse duration from 250 to 1000 ms during the contact welding on the structural and mechanical characteristics was studied.

Further, the samples of the joints were processed by drilling, turning and grinding, while the total thickness of the titanium layer cut from the surface was 0.1 mm. In the course of machining, the parameters under which the obtained "Chromium steel-base – Ti-coating" system retained the required geometric parameters were determined.

The surface morphology of the samples was studied using optical microscopy (OM). To analyze the structural changes, the cross-sections of the composite "Steel – Titanium" structure were made. The Vickers method (at 50–200 gf) was used to test hardness. Measurement of the microhardness HV ensured the control of residual stresses in the welding region and the region of thermal influence.

3. Results
With a pulse duration of about 250 ms, a weld joint was formed with a low adhesive strength, which was observed during the subsequent machining. The titanium plate at the turning was separated from the steel base. When the pulse duration was increased to 500 ms, a stable attachment of titanium to the steel was observed, and during further machining the composite structure retained its integrity (Figure 2a). An increase in pulse to 750 ms also ensured a stable attachment of titanium on the steel, however, a more intense heating was observed in the area exposed to the electrode. This led to the oxidation of titanium and growth of hardness, which worsened the subsequent machining, i.e. there was an increased wear of the metalworking tool. With a pulse duration of about 1000 ms, the titanium plate melted to the full depth, which was accompanied by significant thermal deformations.
Figure 2(a, b). Top view of the sample of the weld joint after machining from the side of the titanium plate 1 (a); a two-layer structure consisting of a steel base 2 and a titanium plate 1 (b).

After machining, which included drilling, turning and grinding, a prismatic structure with a central hole was formed (Figure 2b). As a result, the contact welding modes were determined, in which the structure retained the required shape without collapsing under dynamic loads.

Thus, the optimal pulse duration equalled 500 ms. At the same time the hardness of the titanium plate was in the range from 290 to 320 HV. In the weld boundary, the hardness reached 450 HV, and the steel base had an average hardness of about 470–490 HV.

Figure 3. The microhardness HV distribution along the section in "Steel – Titanium" structure.

The initial hardness of the steel base was about 220–230 HV. Thus, under the influence of a powerful electric current pulse with an energy from 1 to 4 kJ, the following processes occurred in the welded joint: heating of the contact surfaces, local melting, phase transitions in the solid state,
including quenching and average tempering. The achieved strengthening of the contact area did not prevent further machining, including drilling and reaming.

4. Conclusion
Thus, the possibility of an effective joining of chromium steel (instrumental class) with commercially pure titanium was shown. As a result, "Chromium steel-base – Ti-coating" composite structure with a high adhesion strength was obtained, which can be further modified, e.g. by gas-thermal methods, to obtain cermet layers and coatings [8].

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