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Structure of Welded Joints Obtained by Contact Weld in Nanostructured Titanium

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Abstract. The paper presents the research of the weld structure of two Ti specimens of the type VT6 that have nano- and submicrocrystalline structures. Electrical contact welding is used to obtain welds. The acicular structure is formed in the weld area. Two types of defects are detected, namely micropores and microcracks.

INTRODUCTION

The widespread use of titanium and its alloys as functional materials in aerospace engineering, nuclear power engineering, and other industries is caused by a combination of their unique physical and mechanical properties—high strength and ductility at low density, corrosion resistance in many corrosive environments, etc. [1–16]. New prospects arise at severe plastic deformation of high-strength titanium alloys that possess important functional properties, which results in the formation of an ultra-fine grained structure (UFG—submicron and/or nanocrystalline structure) in these materials. These factors must be considered at manufacture of products from such alloys when welding has to be used.

In order to obtain high performance characteristics of welded joints concentrated energy flows must be applied, which allows to minimize heat input into welded products and to localize the release of energy in weld zones [6, 7, 15]. Thereby, it is possible not only to obtain welded joints with high performance characteristics, but also to achieve welding of titanium with other difficult-to-weld materials.

Peculiarities of welding of titanium alloys using laser and electron beams have been studied the most. At the same time, improvement of the equipment technology for contact welding [16] made it possible, in some cases, to transition to electron-beam welding. Considering the fact that in some cases parts can be miniature, in particular in aerospace engineering and in medical industry, the possibility of applying contact (point) welding is of great interest.

Among titanium alloys the most promising for these purposes is the alloy VT6. This alloy belongs to high-strength alloys with an increased strength in the annealed condition ($\sigma_в$ = 1100÷1250 MPa) and a satisfactory ductility (δ = 5÷25%); besides, it responds well to welding [1–3]. This means that the alloy does not substantially change its properties under the influence of the thermal cycle of welding. This alloy belongs to two-phase alloys ($\alpha + \beta$) and is doped with Al and V.

There are many studies devoted to the weldability of high-strength alloys VT6, VT14, VT15, VT22, VT23 using different methods (arc, laser, plasma, etc.) [1–7]. A peculiarity of the submicrocrystalline microstructure of titanium

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is a large number of extinction contours, indicating a high level of internal stresses arising in specimen as a result of a severe plastic deformation [8–13].

There are various methods for production of an ultrafine-fine grained structure of titanium alloys. The thermal stability of alloys in such a state of alloys has a high threshold value. Thus, for example, the microstructure of submicrocrystalline titanium rods obtained using the combined *abc*-pressing method with the subsequent multistage rolling is thermostable up to a temperature of 350°C [5].

In this regard, the study of changes in the microstructure of weld joints of ultrafine-grained titanium alloys after different types of welding (laser, electron-beam, electric-contact, etc.) are of interest. The aim of the work is to study the changes in the microstructure in the weld zone during an electric-contact welding of nano and submicrocrystalline specimen of titanium alloy VT6.

MATERIAL AND EXPERIMENTAL TECHNIQUE

A study of macro and the microstructures of a weld zone (WZ), a heat affected zone (HAZ), and a base metal was carried out using an optical microscope OlimpusGX51 (images are shown in Fig. 1).

The test material was an industrial two-phase alloy VT6 with a standard chemical composition GOST 19807-91. Development of a submicrocrystalline structure of titanium alloy VT6 was carried out by means of severe plastic deformation on a universal testing machine INSTRON using the *abc*-pressing method in the temperature range of $(0.40 \div 0.35) \times T_{ml}$ (T_{ml}—the melting point of titanium is 1,933 K).

The choice of the strain temperature range was conditioned by severe dynamic recrystallization processes occurring in this temperature range [2]. At the first stage, the degree of plastic compressive strain reached 200% at the temperature of 773 K in two passes. At the second stage at the temperature of 623 K, it amounted to 220%.

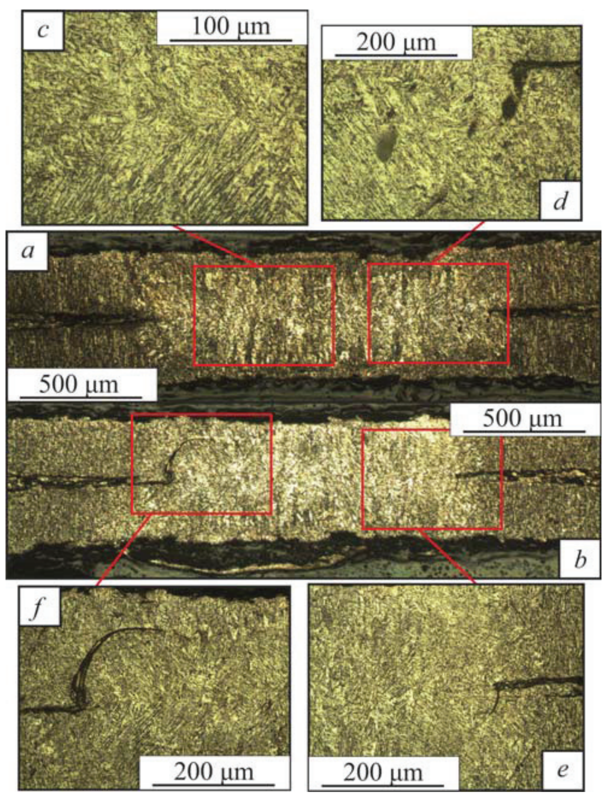

FIGURE 1. Cross-section of studied samples (a, b), the metal structure in the central region (c), pores in the contact zone (d), discontinuities along edges of the contact (f, e)

At the third and final stage, the pressing was carried out at the temperature of 673 K in one passing, and the degree of plastic strain amounted to 120%. The total degree of compressive strain after these three stages reached the values of 540%.

STRUCTURE OF THE FRACTURE OF FAILED JOINTS

Strength tests of the weld joint showed a high quality of the contact. The failure occurred along the contour of the weld spot inside one of the weld plates (Fig. 2). The structure of the fracture appeared to have a number of peculiarities.

The fracture of the weld joint of the studied titanium alloy in the initial nanocrystalline state takes place in two different zones (Fig. 2a).

In the zone *A* that is located on the boundary of the weld spot, the fracture takes place in the shape of an intercrystallite brittle cleavage (Figs. 2a and 2b). The fracture in this area is arranged parallel to weld plates.

In the zone B that is located inside the weld spot, the fracture takes place in a ductile manner with a characteristic pit-like structure of the fracture (Figs. 2a and 2c). The fracture in this case is arranged perpendicular to weld plates.

As seen from Fig. 2a, in the outermost area of the weld spot the structural elements of the metal are arranged at the angle of 45° to the surface of plates, but the structure changes towards the center of the weld point, and within the weld area it is represented by “dendrites” arranged perpendicular to the boundary of plates. Thus, the boundaries of these areas have a structure gradient, which causes failure precisely in these areas. At the same time, in the zone A the fracture takes place in the shape of a brittle cleavage and in the zone B the fracture is ductile.

RESULTS AND DISCUSSION

The studies of the structure of the weld joints by the optical metallography method have shown that the initial grain structure of the specimen in the weld zone undergoes significant changes (Figs. 1a and 1b). The metal structure in the weld zone is needle-like, indicating rapid cooling and, as a consequence, an occurrence of hardening effects (Fig. 1c).

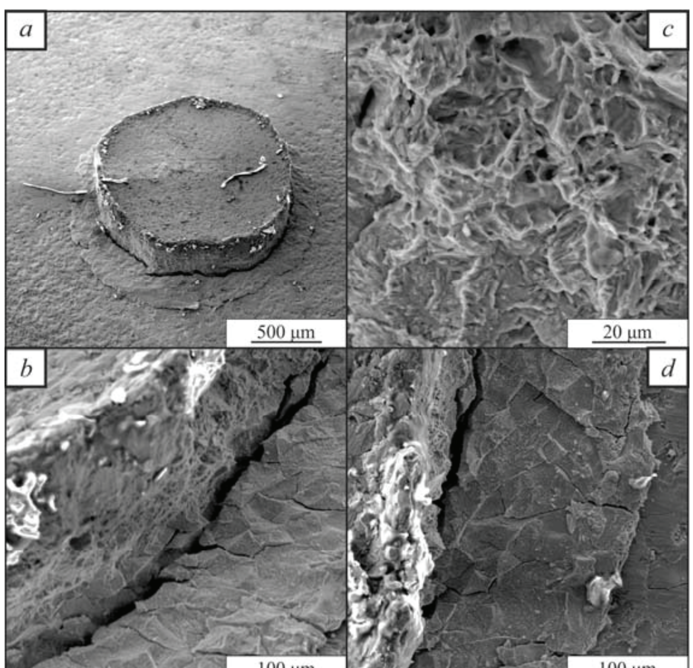

FIGURE 2. Failure of the welded joint of titanium alloy VT6 in the nanostructured initial state (a), characteristic structure of the main zones of the sample fracture (b), ductile (pit) fracture in the zone *A* (c), intercrystallite fracture in the zone *B* (d)

Defects presented in Figs. 1d, 1e, and 1f are observed along the edges of the weld zone. The defects are divided into pores (Fig. 1d) and microcracks (Figs. 1f and 1e) of different sizes. The presence of defects is presumably caused by the presence of oxides on the surface of the plates prior to welding, resulting in an incomplete mixing of the plates in the boundary layer of the material and in formation of microcracks.

The presence of a microrelief on the surface of the plates after the electroerosive cutting is also essential. The microrelief is represented by small shells, which conditions the presence of pores inside the metal during welding.

Thus, welding of titanium alloy VT6 in the submicrocrystalline state using the electric-contact welding method has allowed forming a strong weld. The structure of the weld is needle-like due to rapid heating from the welding bath followed by rapid cooling. Due to the gradient structure, the relief of the failure surface along the weld joint corresponds to the combined failure that includes a ductile failure and a brittle failure.

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