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The problem of intermixing of metals possessing no mutual solubility upon explosion welding (Cu–Ta, Fe–Ag, Al–Ta)

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ABSTRACT

On the basis of the results obtained for joints of dissimilar metals such as copper–tantalum and iron–silver, the reason of immiscible suspensions mixing upon explosion welding has been cleared out. It has been found that the interface (plain or wavy) is not smooth and contains inhomogeneities, namely, cusps and local melting zones. The role of granulating fragmentation providing partitioning of initial materials as a main channel of input energy dissipation has been revealed. It has been shown that in joints of metals possessing normal solubility the local melting zones are true solutions, but if metals possess no mutual solubility the local melting zones are colloidal solutions. Realization of either emulsion or suspension variant takes place. The results can be used in the development of new joints of metals possessing no mutual solubility.

1. Introduction

Explosion welding process is very high-velocity and a little similar to other ways of materials junction, but some of joints could not be obtained in other manner. The characteristic times are duration of the welding approximately 10^{-6} s, rate of deformation 10^4–10^7 s^{-1}, cooling rate 10^5 K/s. This process, being outwardly simple one, has a very complex physical nature, and thus requires not only a detailed structural analysis, but also a new approach. With all the variety of materials and welding regimes the key issue is a problem of intermixing in the transition zone near the interface [1–3]. Intermixing takes place as a result of a strong external action, which involves large plastic deformation (including pressure, shear components, rotatory moments of the stress, strain inhomogeneity, etc.), friction of surfaces, the effect of cumulative jet and some other factors. But so far it remains unclear how even at such a strong external action intermixing occurs in so short time while welding. More urgently the question rises when we are talking about materials that possess no mutual solubility, even in the liquid state.

Welded joints of metal-intermetallic possessing a normal mutual solubility in both liquid and solid states had been investigated previously [4–7]. Commercially pure titanium was chosen as a metal, and orthorhombic titanium aluminide based alloys ("aluminide" for short) were selected as an intermetallic compound. Depending on welding conditions, different joints have been obtained and for convenience are entitled as follows: (A_w), (A_p), (B_w), (B_p), where the subscript indicates the interface shape (plain or wavy). Orthorhombic alloys containing 16 at. % Nb and 23 at. % Nb were used in joints of A type and B type,

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correspondingly. In some joints a melting along entire interface was observed, while the local melting zones with vortex structure take place for others. In any case, the melts are true solutions.

To find out how important is the presence of mutual solubility of the starting materials for explosion welding, metals (copper–tantalum, iron–silver), forming immiscible suspension in liquid state, were selected. “Why the intermixing of immiscible suspensions occurs?” is the question which we try to answer in this paper.

2. Experimental

The welding both of investigated joints and titanium–aluminide ones has been carried out by Central Research Institute of Structural Materials “Prometey,” St. Petersburg, Volgograd State Technical University, OJSC Ural Plant of Chemical Engineering, Ekaterinburg. The welding was carried out using different schemes and parameters, and on the basis of the results obtained, joints to be studied had been selected. We restrict our considerations by giving only the basic welding parameters in Table 1.

The joint (E_p) of aluminum–tantalum metals, which possess normal mutual solubility, is used for comparison with joint (C_p) copper–tantalum metals which possess no mutual solubility. Plain interface was observed for both joints.

The metallographic analysis was carried out using an Epiquant optical microscope equipped with a computing system SIAMS. The study of the microstructure was performed employing JEM 200CX and SM-30 Super Twin transmission electron microscopes, Quanta 200 3D scanning electron microscope. The surface roughness of the starting materials was studied using optical profilometer Zygo NewView 7300. Equipment of Center of Collaborative Access “Diagnostics of structure and properties of nanomaterials” (Belgorod), such as OLYMPUS GX51 optical inverted microscope, Quanta 600 scanning electron microscope (the maximum resolution of about 2 nm), and ion gun Fashione 1010 ION MILL, was also used.

3. Results

The results of studies into two phenomena, fragmentation and formation of colloidal solutions, will be presented below. The term “fragmentation” is generally used for formation of disoriented microvolumes inside a substance. Usually fragmentation (dislocation cells, tangled configurations, bands, recrystallized grains) is observed after severe plastic deformation. Such kind of fragmentation hereinafter referred to as “traditional” is observed also after explosive welding. However there is no flying away of material particles during traditional fragmentation. This flying away of particles is observed during explosive welding and is believed to be analog to flying away of fragments upon explosion. Fragmentation during explosive welding which includes formation, flying away and partial consolidation of particles, has been called by us “fragmentation of granulating type” or “granulating fragmentation” (GF) in short [6]. Both types of fragmentation are observed in all studied compounds regardless of the initial metals solubility.

Mixing inside the local melting zones depends on this circumstance. Normal solubility provides for mixing at the atomic level. In the absence of mutual solubility the mixing process is different. In this case, as shown below, mixing of particles (or drops) occurs and a colloidal solution forms and then freezes. In colloidal solutions the dispersed phase is singled out. This phase is distributed in dispersed medium. Suspension and emulsion are forms of colloidal solutions for the studied welds. In case of suspension the dispersed phase is a solid, and the dispersed medium is a liquid, while in case of emulsion both dispersed phase and dispersed medium are in liquid state.

In investigated joints under different regimes of explosive welding there have been observed interfaces of different types: plain in (C_p) and (E_p) joints, and wavy in (C_w) and (D_w) joints. Figs. 1 and 2 show the optical images (OM) and scanning electron images (SEM) of the investigated interfaces.

Images of the transition zone in (C_p) copper–tantalum joint are given in Fig. 1a and b [8]. It is clearly seen that the interface is almost plain (Fig. 1a), and contains cusps, which are well-defined in Fig. 1b. The size of cusps is about 5–10 μm. Profilometer was used to measure the surface roughness of metals prepared for welding. The average roughness is approximately 0.61 μm for tantalum and 0.41 μm for copper. It means that the size of cusps on the surfaces after welding is 10–20 times greater than the initial roughness. The transition zone of (E_p) aluminum–tantalum joint is depicted in Fig. 1c and d. The interface is also almost plain, but contains weak waves. From Fig. 1d, wavelength is approximately 30 μm, and amplitude is 10 μm.

In addition to the welding regime (C_p) used above, the copper–tantalum joint has been obtained using a different mode (C_w). In this case interface is wavy, with wavelike profile having an asymmetry relative to the vertical plane (Fig. 2a and b). The wavelength and the amplitude are approximately 270–350 μm and 60–65 μm, correspondingly. In Fig. 2b it is clearly visible local melting zone with vortex structure. The interface of (D_w) iron–silver joint is presented in Fig. 2c and d. Wavy interface shape is

Table 1 – Basic welding parameters.

Designation	Base plate (thickness, mm)	Flyer plate (thickness, mm)	γ, collision angle (deg.)	V_c, collision velocity (m/s)	V_i, impact velocity (m/s)
C_p	Copper (4.0)	Tantalum (1.0)	5.22	2680	234
C_w	Copper (3.5)	Tantalum (0.1)	11.8	2125	440
D_w	Iron (1.5)	Silver (1.0)	15.6	1910	520
E_p	Tantalum [a] (0.5)	Aluminum (7.0)	8.6	2000	300

[a] Base tantalum plate was placed on the steel plate.