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STUDY OF STRUCTURAL TRANSFORMATIONS OCCURRING IN THE METAL COMPOSITE AFTER EXPLOSION WELDING

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ABSTRACT

The method of explosion welding is possible to obtain a variety of bi-metal, multi-layered and composite materials with improved strength, corrosion-resistant, heat-resistant and other properties to meet the needs of industry.
Materials for welding alternating sheets were: 1) of the maraging steel 03H12N8K5M2YUT and aluminum alloy D16 (0.5 mm and 1,0 mm thick, respectively), 2) of the maraging steel 03H12N8K5M2YUT, titanium alloy OT4-1, D16 aluminum alloy, titanium alloy and maraging steel, and 3) of the alloy BrBNT - maraging steels - alloy BrBNT - maraging steels - alloy BrBNT. Composites were formed of the five-layer plates.
Microheterogeneous structure has been detected of the transition zone. The transition zone is inhomogeneous and has a thickness of about 15-20 microns. The methods of microprobe analysis (MRSA) and scanning electron microscopy (SEM) has studied the structure of the transition zone. It should be noted that in some composite materials in the collision of two crystalline solids in a narrow near-contact zone the formation of wave-like areas was observed. It is arising from the interaction of shear and rotational modes of plastic flow of metals. High-energy short-term exposure can provide a connection of dissimilar materials with different mutual solubility, wettability, and tendency to form chemical compounds.

1. INTRODUCTION

Explosive welding is a high-intensity short-term impact and allows a variety of bimetallic compounds, layered and composite materials with improved strength, corrosion-resistant, heat-resistant properties for the industry. The term "explosive welding" is commonly understood as a phenomenon lasting compounds colliding at an angle of surfaces of metal plates, which are accelerated to high velocities of detonation products of explosives. The main object of research is the transition zone near the interface of two bonded materials. It defines the structure of the transition zone of the welded joint strength of materials. Researchers 1-4, working in this field have not reached a consensus on the nature of the connection with explosion welding. We discuss these hypotheses as 1) the formation of local melts in the transition zone, with the result that

[1)] Professor, [2)] Young scientist, [3)] Doctor, [4)] Postgraduate student, [5)] Postgraduate student, [6)] Postgraduate student there is mixing in the melting zone, which leads to obtaining a lasting weld, 2) severe plastic deformation of the boundary layers, and 3) the formation of new phases, etc. Apparently, the lack of consensus about the structural changes in the transition zone due to the nature of connected components, their dimensions and welding parameters, have require in each case a preliminary study. This work is devoted to studying the structure of metals and transition zones and to study the mechanism of mixing.

2. MATERIALS AND METHODS OF RESEARCH

Materials for welding alternating sheets were: 1) of the maraging steel 03H12N8K5M2YUT (ZI 90-VI) and aluminum alloy D16 (0.5 mm thick and ≈ 1,0 mm, respectively). 2) of the maraging steel 03H12N8K5M2YUT, titanium alloy OT4-1, D16 aluminum alloy, titanium alloy OT4-1 and maraging steel, and 3) of the alloy BrBNT - maraging steels - alloy BrBNT - maraging steels - alloy BrBNT. Three-and five-layer composite materials were formed of the plates.

The following methods were used to study the processes occurring in the investigated composite materials: microstructure, microprobe, electron microstructural analysis and mechanical properties of the joined metals and composites in general.

Metallographic analysis was performed using an optical microscope OLYMPUS GX-51 at magnifications of 250-500 times.

Microprobe analysis was carried out in a scanning electron microprobe Philips SEM 535 with the prefix Jeol JSM-649LV microanalysis system Oxford Instruments Inca Energy 350.

Fractographic studies were carried out from the surface of samples exposed to a tensile test and bend in a scanning electron microscope Philips SEM 535 with a resolution of ~ 50 Å at an accelerating voltage E = 25 kV.

Microhardness measurements were performed on Micromet microhardness 5103. The test system is designed to determine the method of Vickers microhardness with a load of 10 to 1000 g.

Mechanical tests were performed on an electromechanical Instron 3380 tensile testing machine. In this case the samples were determined: temporary resistance at break (σ_B, MPa), elongation (δ,%); relative narrowing of the cross-section at break (ψ,%); yield stress ($\sigma_{0,2}$, MPa). To evaluate the adhesion strength of laminated composite materials was used in the bending test.

3. RESULTS AND DISCUSSION

The microstructure of the materials in the initial state is shown in Fig. A. After quenching from temperatures of single-phase γ-region (900-1000 °C) structure of the investigated steel 03H12N8K5M2YUT is virtually 100% martensite. Tetragonality of martensite due to the low carbon content is negligible. The structure of the steel is given by the so-called "massive martensite" or replacement martensite. Microstructure of hardened steel 03H12N8K5M2YUT shown in Fig. 1, a. The microstructure of quenched alloy consists of grains BrBNT α-solid solution. α-phase located at grain boundaries (lighter component) and within the grains of α-solid solution (Fig. 1b). Some grains may be present twins quenching cooling.

Alloy OT4-1 belongs to a class of pseudo-α in structure (Fig. 1c). The structure of alloy OT4-1 system Ti - Al-Mn at room temperature before α-phase and a small amount of β-phase due to the additional doping of manganese. In this structure there is α-phase (light) in a mixed-type globular structure of the alloy OT4-1.

The structure of alloy D16 (Fig. 1d) in addition to the main matrix phase α, the particles are intermetallic phases CuAl2. The latter may reside in the bulk or at grain boundaries of α-phase. Thus the basic structure (and phase) component of this alloy is α-solid solution consisting of copper and aluminum, which has an fcc lattice.

When welding using the parallel arrangement of the plates and the following welding parameters: γ = 20-30°; Vd = 2450 m/s, where γ - the angle of impact, Vd - the detonation velocity. The height of the layer of explosive was 20 mm. The gaps between the welded plates, 2 mm.

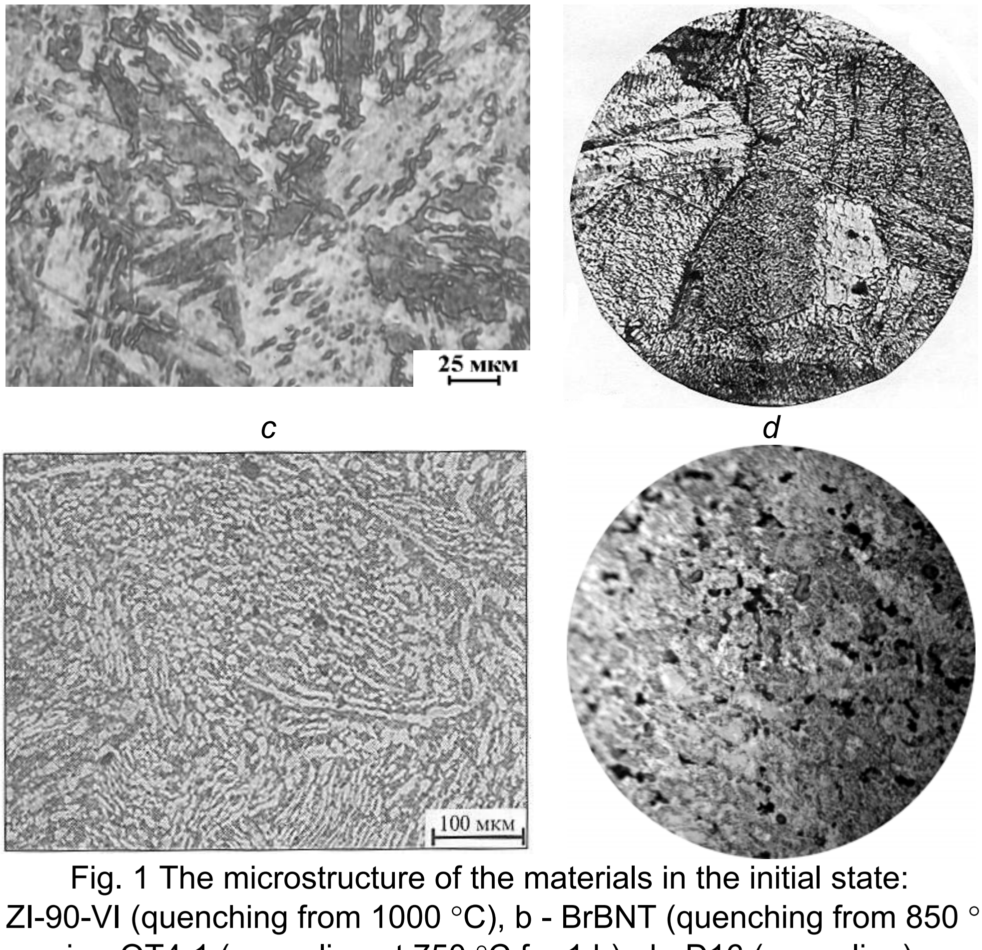

Fig. 1 The microstructure of the materials in the initial state:
A - ZI-90-VI (quenching from 1000 °C), b - BrBNT (quenching from 850 °C);
in - OT4-1 (annealing at 750 °C for 1 h), d - D16 (annealing)

3.1. Composite I: D16 - 03H12N8K5M2YUT - D16

Three-layer KM obtained by explosion welding steel plates 03H12N8K5M2YUT D16 and a thickness of 1 mm and 0.25, respectively. In Fig. 2 shows a cross section of the resulting composite. After the explosion welding layer thicknesses were as follows: alloy D16 - 0.87 mm, steel 03H12N8K5M2YUT - 0.18 mm.

At the boundary between the materials can be seen the lighter areas, apparently of a different composition. Surface roughness is practically not observed. Investigation of the distribution of microhardness over the cross section of three-layered composition showed that the bright regions are more depleted zone alloying elements duralumin, which has a lower supersaturation of alloying elements. Microhardness of duralumin is about 200 HV_{10}, while the microhardness of maraging steel is 500 HV_{10}. The mechanical properties of the composition I after the explosion welding are as follows: σ_B = 560 MPa, $\sigma_{0,2}$ = 456 MPa, δ = 9%. Testing of composite materials and raw materials in tension showed that the strength characteristics of the composite material is slightly lower strength properties of maraging steel, but higher than the matrix material, in this case, duralumin.

a *b*

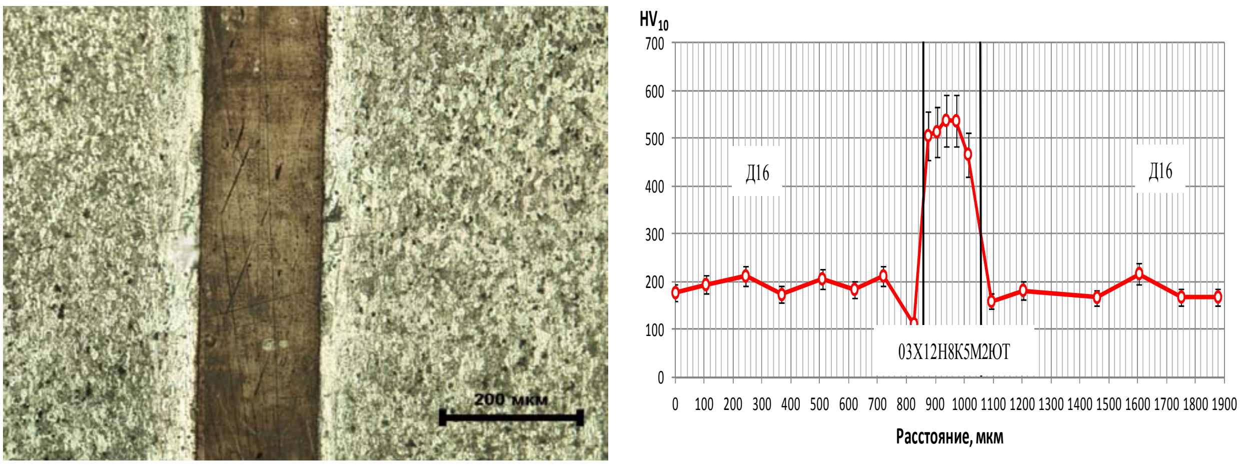

Fig. 2 Microstructure of (a) and the distribution of microhardness over the cross section of the Composite-I

The numerical examples have illustrated that the proposed finite elements could be very useful for geometrically nonlinear analysis as well as free vibration …

3.2. Composite I: D16 - 03H12N8K5M2YUT - D16

Fig. 3 shows a cross section of five-layer welded joint.

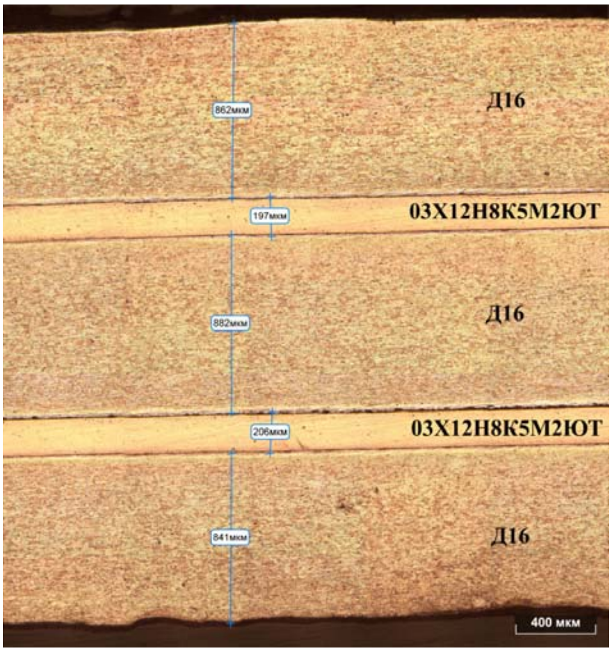

Fig. 3 Microstructure of of the Composite-II

Metallographic analysis revealed the presence of three zones: zone of maraging steel with the structure of a packet martensite (Fig. 4c), the transition zone between the layers of aluminum-steel (Fig. 4b) and the zone - duralumin (Fig. 4a).

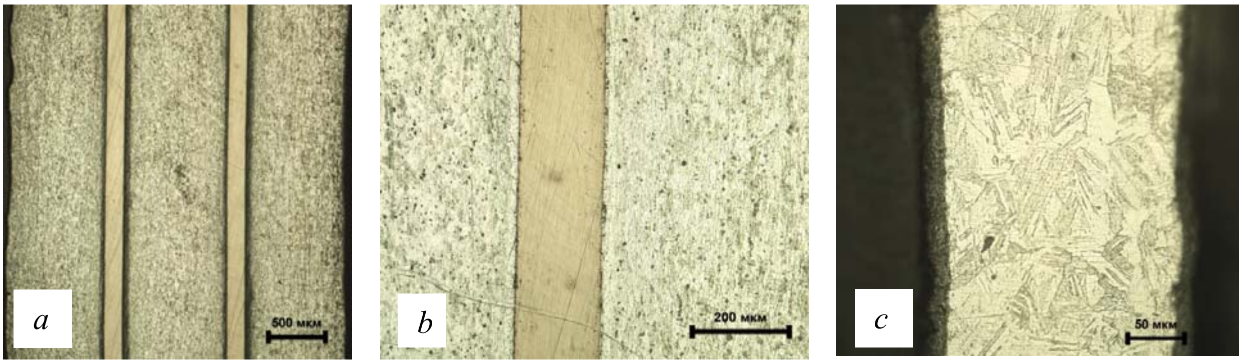

Fig. 4 The microstructure of the Composite II after the explosion welding
(after etching in different etchants)

Detected microheterogeneous structure of the transition zone. The transition zone is inhomogeneous and has a thickness of about 15-20 microns. To elucidate the structure of the transition zone were carried out microprobe analysis (MRSA) and scanning electron microscopy (SEM) (Fig. 5 and 6). Irregularities of the surfaces separating the minor, however, we note the formation of very thin transition layer containing a high content of aluminum and 85 at. %, and the atoms of iron, chromium and nickel. In appearance the discharge can be assumed that this layer of intermetallic phases.

a b

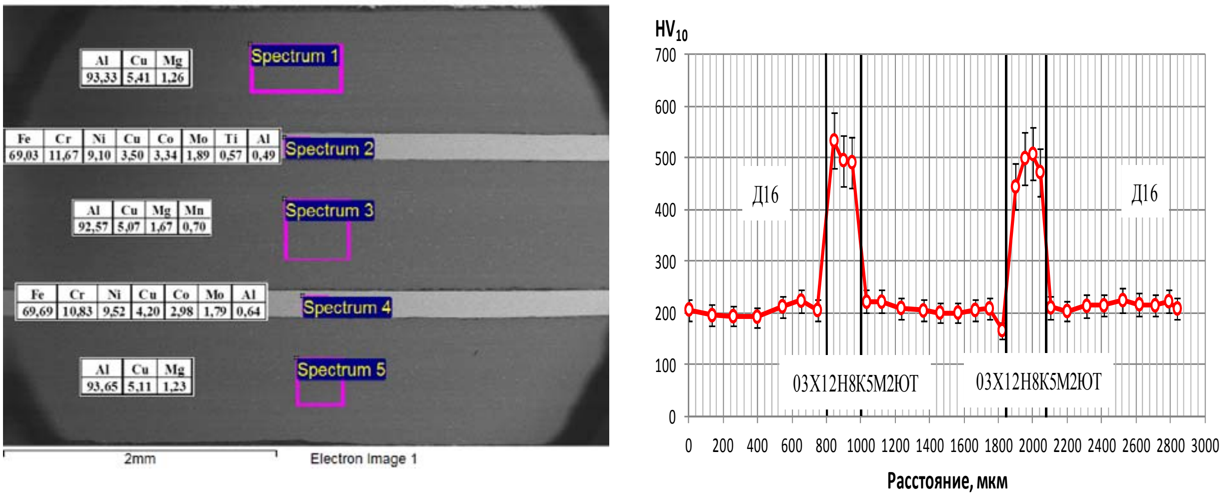

Fig. 5 Microprobe analysis of Composite II (a) and the distribution of microhardness over the cross section (b)

For measurements of microhardness over the cross section of five-layer composition could not get into the area, as it has a very narrow range of existence (Fig. 5). Microhardness of duralumin is about 200 HV_{10}, while the microhardness of maraging steel is 500 HV_{10}.

Microfractographic studies have revealed characteristic patterns of destroyed ductile fracture in all areas of the composite section (Fig. 7).

a b

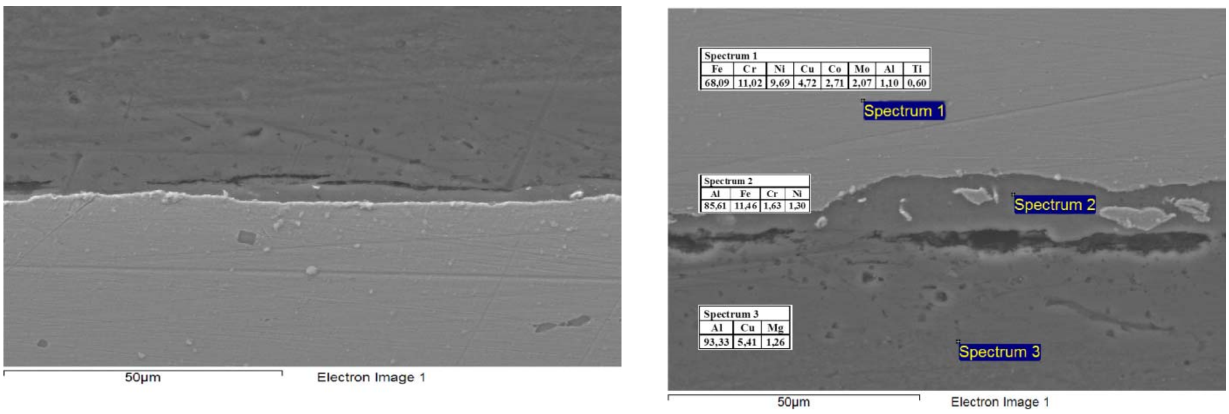

Fig. 6 Microprobe analysis joint zone composition II:
D16 (top) + maraging steel (bottom) (a); and maraging steel (top) + D16 (bottom) (b)

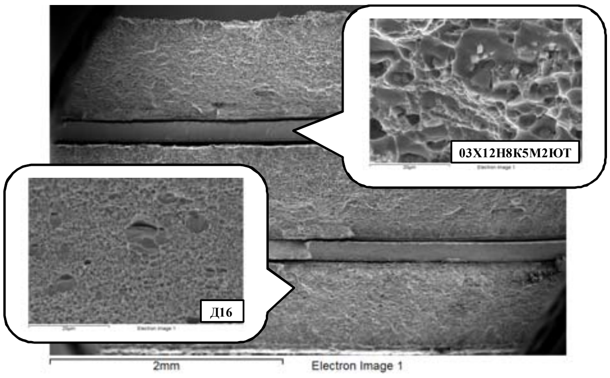

Fig. 7 Composite III: BrBNT-03H12N8K5M2YUT - BrBNT-03H12N8K5M2YUT - BrBNT

Fig. 8 shows a cross-section of the welded joint. The transition zone of the composite is different from those described above, first of all, wavy interface, the amplitude and wavelength in different layers with respect to the shock wave. This is explained by the fact that the upper welds are subjected to more intense dynamic loading. The length and amplitude of the wave is about: the upper wave - 94 and 23 microns for the average - 71 and 9 microns for the bottom - 304 and 94 microns, respectively.

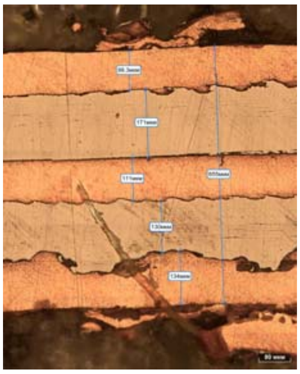
Fig. 8 Microstructure of the Composite III after explosion welding

Microprobe analysis revealed the following spectral analysis of the layers (Figure 9-10). Irregularities of the interfaces can be described as projections of one metal to another. At the boundaries of visible regions of gray, whose composition was determined by electron microprobe analysis (Fig. 10 c). These results suggest that these zones have been formed as a result of intensive mixing steel and beryllium copper. The structure of the mixing zone contains iron - 41.5%, 40.5% copper, chromium - 6.5% Beryllium - 6.0% and 5.4% nickel.

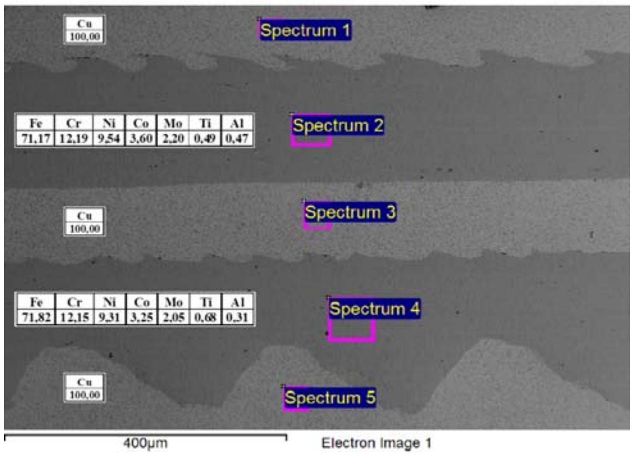

Fig. 9 Microprobe analysis and the general appearance of the composite III

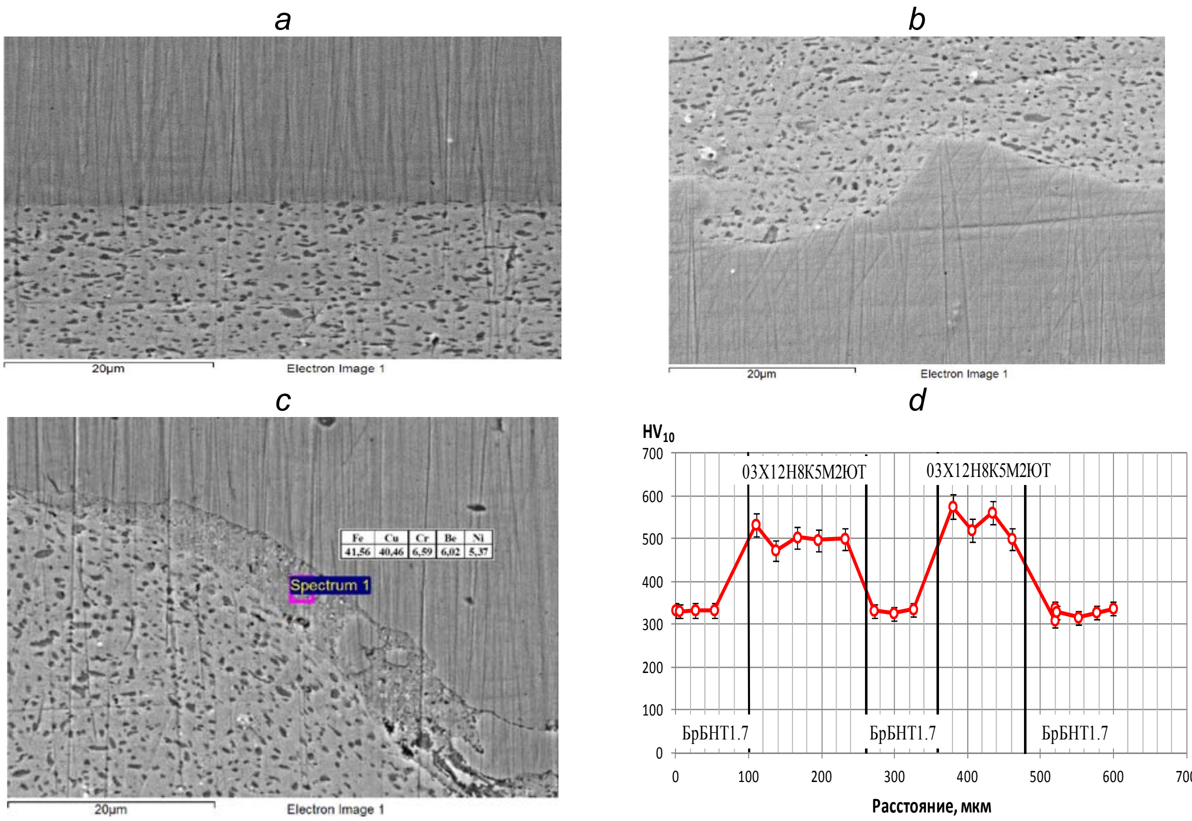

Fig. 10 Microprobe analysis of composite zone compound III:
steel (top) + BrBNT (bottom) (a, c); and BrBNT1 (top) + steel (bottom) (b)

This indicates that during the welding process through the interface is an intensive mass transfer as a means of wave deformation with the formation of multiple protrusions of one material to another on the resulting wave-like boundary and, possibly due to the melting of materials at the interface and the intense circulation of the melt in the case of formation of zones of local melting of vortex formation observed in them.

Distribution of microhardness over the cross section of composition III after explosion welding is shown in Fig. 10 When performing measurements, the microhardness of the transition zone could not be measured. Microhardness of bronze is about 300 HV_{10}, while the microhardness of maraging steel is 500 HV_{10}.

3.3. Composite IV: 03H12N8K5M2YUT - OT4-1 - D16 - OT4-1 - 03H12N8K5M2YUT

In Fig. 11 shows the cross section of 5-ply welded joint. As shown by metallographic studies along the entire profile of compounds of the metals had a good mix of components, without pores and discontinuities. After the explosion welding layer thicknesses were: OT4-1 - 0.89 mm, D16 - 0.87 mm, steel 03H12N8K5M2YUT - 0.18 mm (Fig. 11).

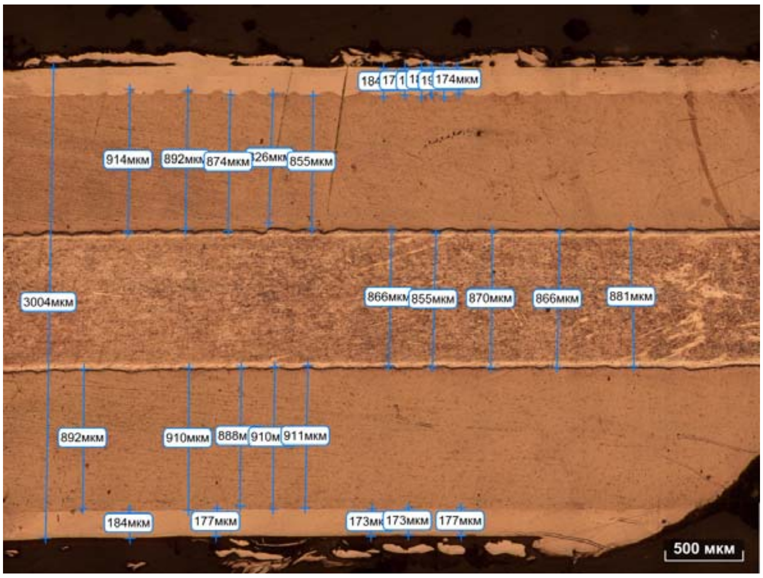

Fig. 11 Microstructure of the Composite VI after explosion welding

The interfaces are typical of explosion welding wavy form. As we move from the upper to the lower weld amplitude and wave length decrease gradually. This is due to the fact that the upper welds are subjected to more intense dynamic loading. In the surface layers of aluminum polygonization processes occur due to heating of local areas. For the development of polygonization processes in titanium heating temperature was inadequate. In this composite, the observed waviness of the shock has a much smaller amplitude and wavelength than in the previously discussed composites. In the process of explosion welding formed a smooth transition zone, more light, which is also a zone of mixing. With the help of Microprobe analysis investigated the structure of the transition zone titanium steel.

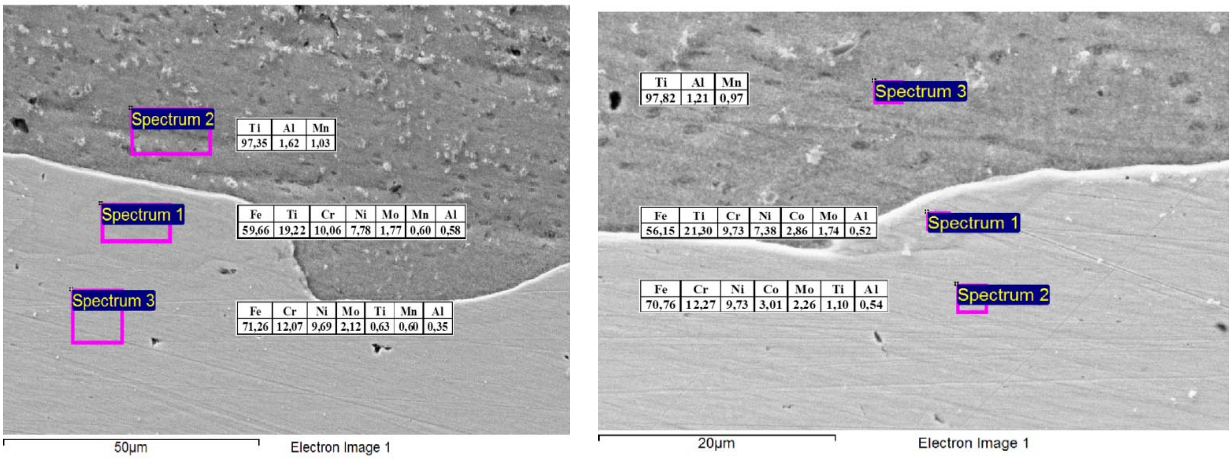

Fig. 12 Microprobe analysis joint zone composition IV: OT4-1 (top) + steel (bottom)

As a result of diffusion in the duralumin formed aluminum-depleted areas (Fig. 13, Spectrum 2). As mentioned above, the formation of these zones is connected, apparently, with the processes of local melting and subsequent crystallization with the release of intermetallic phases, which leads to a decrease in the microhardness of the zone.

a *b*

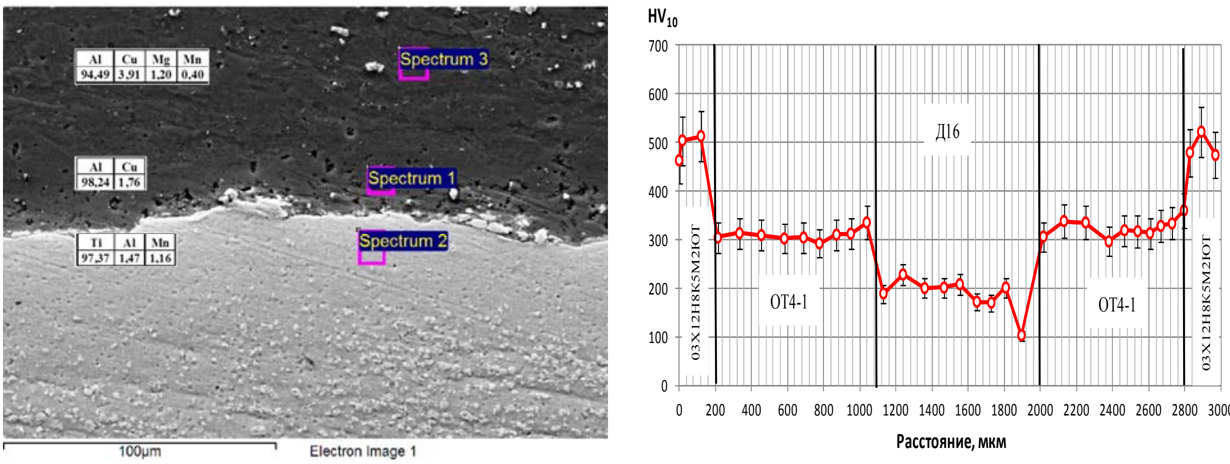

Fig. 13 Microprobe analysis joint zone composition IV (a) and the distribution of microhardness over the cross section of the composite (b) D16 (top) + OT4-1 (bottom)

Distribution of microhardness over the cross section of composition IV after explosion welding is shown in Fig. 13 b. The microhardness of the order of duralumin 200 HV_{10}, the microhardness of titanium alloy 300 HV_{10}, while the microhardness of maraging steel is 500 HV_{10}. The mechanical properties of the composition IV immediately after the explosion welding (sample IV-0) and after annealing at 500 °C (sample IV-4) are shown in the table. Tests at the inflection point showed that the number of kinks in all of the above composites is from 7 to 10. Fractographic and microstructural studies of stratification in the composites were found.

Thus, this study obtained composites explosion welding of different materials showed that the explosive welding is a process that allows to combine dissimilar materials. Based on structural studies can be concluded about the high quality welds. In the process of welding metal materials undergo significant structural changes, which include severe plastic deformation of the boundary layers and the formation of new phases. At the boundary of dissimilar materials in the transition zone is observed intense mixing, which leads to a change in the chemical composition of the material, sometimes with the formation of new intermetallic phases.

Table 1: The mechanical properties of the composite IV

#	σ_B, MPa	$\sigma_{0.2}$, MPa	δ, %
IV-0	682	525	9
IV-4	754	587	7

CONCLUSION

1. The processes occurring in the investigated composite materials at the interfaces.
2. It is established that the explosion welding process through the interface is an intensive mass transfer through both the deformation of wave form with a set of microscopic one material to another on the resulting wave-like border, and by means of melting materials at the border. Such a pattern is observed in composites: III, IV, whereas in the composites I and II of the surface boundary was virtually flat.
3. Structural studies and tests on the inflection indicate a high quality weld. The strength of the composites exceeds the strength of the matrix[1].

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