NOTATION

E, electric field intensity; d_t, m, q, diameter, mass, and charge of a particle; g, acceleration of gravity; h, interelectrode distance; Y, dimensionless transverse coordinate; β, local volume concentration of particles; ε_0, ε, dielectric permittivity of a vacuum, relative dielectric permittivity of gas; ρ, density of material. Subscripts: t, particle; y, projection of vector on Oy axis.

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SOME SPECIAL FEATURES OF THE MASS TRANSFER OF THE LIQUID PHASE IN COMPOSITE MATERIALS BASED ON TUNGSTEN AND TITANIUM CARBIDES

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We investigated the phenomena of absorption of molten cobalt by the triphase composite (Ti, W)C—WC—Co and the moving forces of this process.

According to existing notions, mass transfer of metallic melts into sintered porous composites occurs under the effect of capillary forces [1, 2], and into nonporous ones under the effect of diffusion [3]. By the investigations of [4] it was proved that in sintered bodies consisting of high melting particles and a binder metal, a third kind of mass transfer is possible, viz., absorption of metallic melts by nonporous composite bodies induced by rearrangement of the high melting skeleton. This process was called migration of the liquid phase [5].

At present migration of the liquid phase is being investigated predominantly in biphase materials. Special features of the kinetics of mass transfer of metallic melts in triphase composites, the mechanism and the moving forces were not studied much.

The present work is intended to shed light on some of these regularities.

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The experiments were carried out with spherical specimens with 10 mm diameter and specimens 5 × 6 × 35 mm in size, made of a composite containing 40.0 vol.% tungsten carbide particles with a specific surface of 1200 mm^2/mm^3, 52.2 vol.% particles of solid solution of titanium and tungsten carbides (Ti, W)C with specific surface of 1258 mm^2/mm^3, and 7.8 vol.% binder metal cobalt. Residual porosity of the specimens did not exceed 0.1%.

In a vacuum furnace at a residual pressure of 0.1 Pa and a temperature of 1610°K the spherical specimens were immersed in a cobalt melt containing 65.0 wt.% Co, 28.16 wt.% W, 4.0 wt. % Ti, 1.84 wt. % C, designated henceforth VTK65. At 1610°K the binder metal in the prepared specimens was present in the form of a cobalt melt identical in composition with VTK65, and the particles of WC and (Ti, W)C formed two combined high melting skeletons. With constant temperature and pressure, which were ensured during the experiments, and also equal concentration of the elements (Co, W, Ti, C) in the liquid phase of the specimens and in the contacting melt of VTK65, we obtained chemical equilibrium of the system specimen—cobalt melt. Under the same conditions specimens 5 × 6 × 35 mm were brought with their 5 × 6 mm side into contact with the melt of VTK65. The holding time was 300, 660, 1200, 1800, 2400, 3000 sec. Before being charged into the vacuum furnace, part of the specimens were subjected on their 6 × 35 mm sides to uniaxial compression of 30 MPa.

In the subsequent experiments we investigated mass transfer of the liquid phase in the chemically nonequilibrium system specimen—molten metal. This was attained by adding to the melt of VTK65 up to 3 wt. % silicon or chromium which are surfactants for the carbides WC and (Ti, W)C. Under these conditions mass transfer of the liquid phase was effected both by diffusion and migration. The distribution of elements along the 6 × 35 mm side was studied by the x-ray spectroscopic method on a device Camscan-IVd, metallographic and stereological investigations were carried out with an optical microscope Neophot-24.

We established that in spherical specimens immersed in a melt of VTK 65, after holding for 50 min the content of liquid phase increased 6 times and amounted to 60 vol.%, at the same time the volume of the specimens increased 2.2 times, and the carbide particles WC and (Ti, W)C were separated. In the initial state the following values were found: specific contact surface WC—WC $S_V^{WC-WC} = 200\ mm^2/mm^3$, specific contact surface (Ti, W)C—(Ti, W)C $S^{(TiW)C-(Ti,W)C} = 267\ mm^2/mm^3$, and specific phase boundary $S_V^{WC-(Ti,W)C} = 567\ mm^2/mm^3$. The specific phase boundary surfaces binder metal—carbide were equal to $S_V^{WC-Co} = 233\ mm^2/mm^3$, $S_V^{(Ti,W)C-Co} = 157\ mm^2/mm^3$. After penetration of molten cobalt the contact surfaces WC—WC, (Ti, W)C—(Ti, W)C and the phase boundary WC—(Ti, W)C practically vanished, the surfaces molten cobalt—carbide phase increased substantially, their specific values increased to $S_V^{WC-Co} = 1120\ mm^2/mm^3$, $S_V^{(Ti,W)C-Co} = 1030\ mm^2/mm^3$. Molten cobalt penetrated into the zone of contact of particles WC—WC, (Ti, W)C—WC, (Ti, W)C—(Ti, W)C, causing recrystallization of particles and rearrangement of the entire high melting skeleton. When the molten cobalt was absorbed, the content of liquid phase in the spherical specimens increased from 10 to 60 vol.%. In this volume of liquid the carbide particles WC and (Ti, W)C formed equilibrium shapes, correspondingly elongated prisms and spheres. The structure of the composite freed itself of the high-energy contact surfaces WC—WC, (Ti, W)C—(Ti, W)C, WC—(Ti, W)C and changed to a more stable state. It follows from these experimental data that in the investigated composite (Ti, W)C—WC—Co at a temperature higher than the melting point of the binder metal, the surfaces solid—solid are unstable, and under the conditions of unbounded volume of liquid phase in chemical equilibrium these surfaces are replaced by the energetically more stable surface solid—liquid. This replacement of surfaces is the moving force of the process of absorption of the liquid phase by the sintered composite. This replacement of surfaces is effected by recrystallization of particles through the liquid phase by the well-known mechanism dissolution—diffusion—precipitation [6].

The specimens 5 × 6 × 35 mm, being in contact through the 5 × 6 mm side with the molten VTK65, absorbed the latter, and as a result the content of binder phase in them increased. The distribution of the content of binder metal along the specimens is described by a dependence that is close to hyperbolic (Fig. 1). After preliminary compression of the specimens, the depth of penetration of the liquid phase was 1.5 times greater than the depth of penetration of the molten VTK65 in comparison with uncompressed specimens (Fig. 1), and correspondingly higher were also the speeds of migration of the liquid in the specimens subjected to preliminary compression. The speeding up of mass transfer of the liquid phase in these specimens is connected with the weakening of the high melting skeleton. Under the effect of uniaxial compression there arose high stresses in the bulk of the specimens in the zone of contact of the high melting particles. This led to the disruption of some contacts, to the appearance of slip lines, to increased concentration of dislocations in the zone of contact

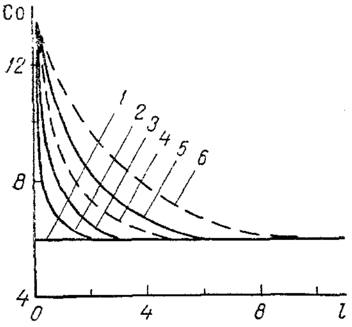

Fig. 1

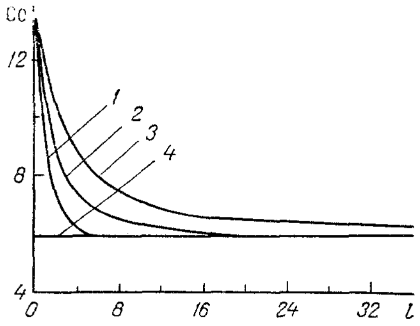

Fig. 2

Fig. 1. Distribution of the cobalt content along the specimens after contact with the cobalt melt (*l* is the depth of penetration of the liquid phase): 1) 0 sec; 2) 300; 3) 660; 4) 660 (preliminary compression); 5) 1800; 6) 1800 sec (preliminary compression). Co, wt. %; *l*, mm.

Fig. 2. Distribution of the cobalt content along the specimens after contact for 1200 sec with cobalt melt (1), cobalt melt with an addition of 3 wt.% Cr (2) and with an addition of 3 wt. % Si (3); 4 is the initial state.

[7]. The weakening of the high melting skeleton had a favorable effect on its rearrangement in the process of migration of the liquid phase. Our investigations showed that the absorption of metal melts by sintered composites leads to the disruption of the high melting skeleton, therefore the action of external factors causing disruption of the skeleton intensifies the process of migration of the liquid.

It follows from the results of the second series of experiments (Fig. 2) that the surfactant additions of Si, Cr intensified the absorption of the molten VTK65. The depth of penetration of molten VTK alloyed with chromium was four times greater than of the composition with chemical equilibrium, and of molten VTK65 alloyed with silicon it was seven times greater (Fig. 2). In these experiments the surface-active elements Si, Cr, diffusing along the boundaries of the carbide particles, weakened the high melting skeleton of the composite and caused recrystallization of the particles. Thus their chemical effect on the high melting skeleton in regard to the final result turned out to be the same as the mechanical effect of compression.

It follows from the presented experimental data that absorption of metal melts by multiphase composite materials occurs as a result of the rearrangement of the high melting skeleton in the process of which the phase boundaries and contact surfaces solid—solid are replaced by surfaces solid—liquid. Physical and chemical methods causing weakening or disruption of the high melting skeleton intensify the process of absorption of metallic melts.

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