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Intrusion Features of a High-Speed Striker of a Porous Tungsten-Based Alloy with a Strengthening Filler in a Steel Barrier

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Abstract—The complex problem of increasing the penetrating power of strikers based on highly porous tungsten composites is considered by improving their strengthening properties by alloying the hardening components under high-speed collision conditions. Using the method of liquid-phase sintering, we fabricated samples of strikers based on a porous WNiFeCo alloy (tungsten + nickel + iron + cobalt), alloyed with tungsten carbide with cobalt (WCCo8) and titanium-tungsten carbide (TiWC). Dynamic tests of the strikers from the developed alloys were carried out at the collision velocity with a steel barrier of the order of 2800 m/s. The penetration depth of the striker based on a porous WNiFeCo alloy doped with tungsten carbides is 30% higher than the penetration depth of a striker of a monolithic WNiFe-90 alloy (tungsten + nickel + iron) with a tungsten content of 90%).

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One of the main areas of the increased penetrating ability of inert metal strikers in metal barriers is the use in their manufacturing of materials with a more perfect set of physical and mechanical properties, as well as an increase in the speed of collision.

Recently, interest has increased in the study of high-speed impacts [1, 2]. Earlier [3], the phenomenon of an anomalously deep penetration of a striker made of steel sawdust in a steel barrier was found, compared to the penetration of a monolithic steel striker with equal mass and diameter moving at a velocity of 3.69 km/s. Further studies [4] showed a steady increase in the penetration depth of strikers from porous materials such as the matrix of steel and WNiFe-90 alloy (tungsten + nickel + iron alloy with 90% tungsten) in a semi-infinite steel target with an increase in porosity and impact velocity ranging from 1.8–2 km/s, which led to the creation of composite porous materials based on high-strength alloys [5]. However, the presence of a a highly porous material makes the impactor unsuitable for throwing at a high speed because of its low strength [6]. With an increasing load during acceleration, the striker in the channel of the trunk might crumble. Consequently, along with improving the strength characteristics of the composite porous materials, it is necessary to solve the problem of the optimal acceleration of the body in a ballistic setup up to high speeds using a sparing loading mode of the body.

To date, ballistic setups have been developed [7, 8], operating in the artillery range of pressures (up to ~ 600 MPa) that allow us to implement the level of velocities of shock elements of 30–50 g mass up to a velocity of 3 km/s, while ensuring a gradual increase of the load in the channel of the trunk.

The objective of this study is to develop composite materials on the basis of a highly porous tungsten alloy having an enhanced penetration ability and strength under the conditions of high-speed collisions with metal barriers.

A possible way to increase the strength of a porous alloy on the basis of a WNiFeCo alloy (tungsten + nickel + iron + cobalt) is by doping it with very strong components such as tungsten carbides.

For this purpose, using the method of high-temperature sintering in a vacuum furnace, we fabricated the samples on the basis of a porous WNiFeCo alloy, doped with a WCCo8 alloy (tungsten carbide + cobalt), namely, WNiFeCo + WCCo8 at different contents of the latter: 20, 30, 40, 60, 70 wt %. The initial density of the WNiFeCo alloy is $\rho_0 = 16.25$ g/cm^3, and WCCo8 – $\rho_0 = 14.76$ g/cm^3.

As shown in Fig. 1, the effect of the WCCo8 content on the density of the WNiFeCo + WCCo8 com-

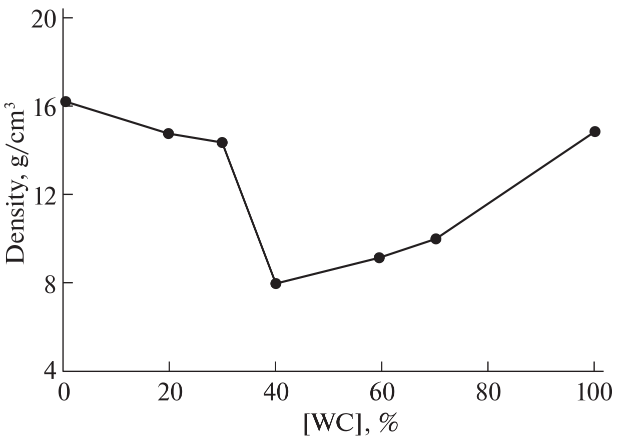

Fig. 1. Effect of WCCo8 content on the density of the composite WNiFeCo + WCCo8 material.

posite is not additive when alloying the initial components. It is seen that an increase in the WCCo8 content in the alloy with WNiFeCo leads first to a sharp drop in the density, and then to its growth.

Investigation of the structure of the fractures of the resultant alloys after the tensile test (Fig. 2) indicates that, as a result of high-temperature sintering, a decrease in the density can be explained by an increase in the porosity of these alloys.

We can see that the WNiFeCo + WCCo8 compositions have a developed porosity, depending on the composition of the components. The composition containing 40 wt % of WCCo8 (WNiFeCo + 40 wt % WCCo8) has the highest porosity (Fig. 2a). The particle size also depends on the composition. For a WNiFeCo + 40 wt % WCCo8 composition, a fine branched honeycomb structure with a particle size of the order of 1 μm is characteristic. A distinctive feature of the structure of the WNiFeCo + 70 wt % WCCo8 composition is that the particles have sharp edges (Fig. 2b) and their size is 1–4 μm.

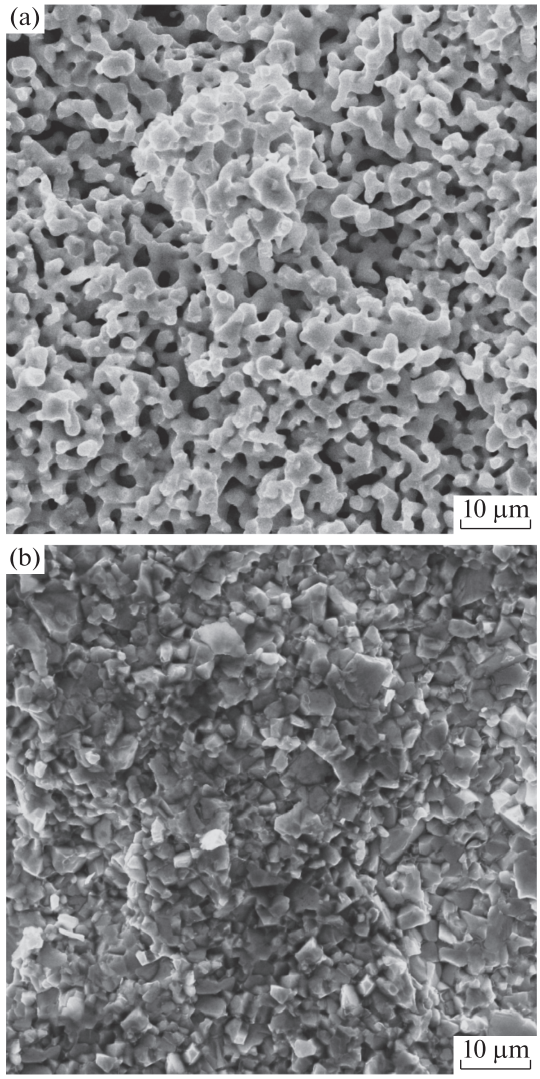

Fig. 2. Structure of WNiFeCo + WCCo8 alloys: (a) WNiFeCo + 40 wt % WCCo8, (b) WNiFeCo + 70 wt % WCCo8.

To compare the penetration depth h of strikers in a steel barrier, two experimental samples were fabricated with equal mass m = 30 g and diameter d = 9 mm, namely, a striker made of a WNiFeCo+ 70% WCCo8 alloy with density ρ_0 = 10.29 g/cm^3 and that of a WNiFe-90 alloy with a density of 17.1 g/cm^3. Because of the different mean density, the strikers have different lengths L. Due to the hardness of the initial sample material (WNiFeCo + 70 wt % WCCo8), the striker was fabricated by the electroerosive cutting method. With the use of a ballistic complex [8], dynamic collision tests of the strikers with a steel barrier 87 mm thick at a velocity of ~ 2800 m/s were carried out. The strikers retained their integrity during acceleration in the channel of a barrel, which confirms the presence of a hardening effect in alloying a porous alloy with

Results of ballistic tests

Образец	V_0, m/s	ρ_{0m}, g/cm3	c_0, m/s	ρ_0, g/cm3	c_0, m/s	ξ, %	L/d	h, mm	Δ, %
WNiFeCo + 70 wt.% WCCo8	2766	15.42	4500	10.29	3676	33.2	5.01	66.2	34.5
WNiFeCo + 10 wt.% TiWC	2817	16.23	4200	11.72	3668	27.8	4.47	65.0	32.1
WNiFe-90	2817	17.1	4000	17.11	4000	–	3.19	49.2	

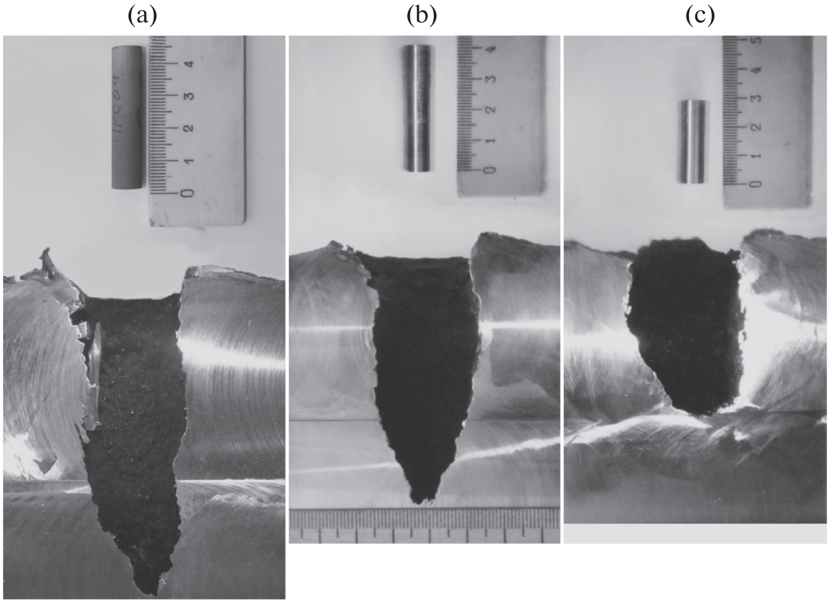

Fig. 3. General view of the striker and the cut of a crater in the steel barrier after the impact: (a) striker of WNiFeCo + 70 wt % WCCo8 alloy, (b) striker of BNiFeCo + 10 wt % TiWC alloy, (c) striker of WNiFe-90 alloy.

strong components. The results of the ballistic tests are shown in the table and in Fig. 3. The relative volume of the voids was determined by the formula

$$\xi = (1 - \rho_0/\rho_{m0}) \times 100\%,$$

where ρ_{m0} is the material density of the matrix (the solid component of the alloy). The table shows the values of the velocity of the sound of the matrix and the porous material, c_{0m} and c_0, respectively.

The depth of the crater formed by the striker made of porous a WNiFeCo + 70 wt % WCCo8 alloy exceeds the penetration depth of the striker of a monolithic WNiFe-90 alloy by $\Delta = 34.5\%$.

The doping of a porous WNiFeCo alloy based on a titanium-tungsten carbide TiWC with a content of 10 wt % also leads to a significant increase in the penetration depth. The depth of the crater formed by the striker of a WNiFeCo + 10 wt % WCCo8 alloy with density $\rho_0 = 11.72$ g/cm^3, mass $m = 30$ g, and diameter $d = 9$ mm is 65.0 mm, exceeding the penetration depth of the striker made of a monolithic WNiFe-90 alloy by $\Delta = 32.1\%$.

The deeper penetration of strikers made of a highly porous WNiFeCo alloy doped with tungsten carbides WCCo8 and TiWC compared to the case of a monolithic striker of a WNiFe-90 alloy, being equal in mass and diameter, is explained by the following factors. First, because of the low average density, the striker has a greater length than the monolithic one. Second, highly porous material has a lower sound velocity compared to a monolithic striker, and the perturbation caused by the impact propagates more weakly upward along the striker, while the velocity damping during penetration occurs much slower. Third, the material of the barrier in the contact zone interacts with the material of the matrix, which contains very hard carbide particles, which leads to an additional abrasive effect.

Thus, new composite materials based on highly porous tungsten alloys doped with tungsten carbide have been developed. The main tendency of increasing the penetrating ability of strikers made of porous materials is confirmed: the strikers of porous composite materials such as WNiFeCo + 10 wt % TiWC and WNiFeCo + 70 wt % WCCo8 are characterized by the penetration depth in steel barriers being 32–34% higher than the corresponding value for a monolithic analog of the WNIFE-90 alloy of equal mass and size.

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