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Composite Materials for Steel Cutting and Concrete Crushing

Yulia Usherenko[a]*, Sergei Usherenko[a], Javad Yazdani[a]

[a]*Belarusian National Technical University, Minsk, 220013, Belarus*

Abstract

The steel based on composite material, created by the stitching of steel matrix by a flow of powder particles. Stitching process implemented in conditions of super deep penetration (SDP) which provides a penetration of the powder particles at speed 1000 m/s on depth up to hundred millimeters. Due to the interaction between the particles and the steel matrix at pulsating pressure above 8-12 GPa a volumetric reinforcing carcass is synthesized.

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Keywords: super-deep penetration, zones of influence, carcass, composite tool materials.

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1. Introduction

The cobalt-tungsten hard alloys show the highest levels of durability among tool materials. Modern high-speed tool steels are inferior to hard alloys in wearing resistance in 100 times, and carbon steels in 200 times. Hard alloys based on cobalt and tungsten carbide are considered as composite materials.

Despite the significant period that has passed since their introduction in the industry (in the twenties of the 20th century) hard alloys still show a unique combination of mechanical properties: toughness, flexural strength and wear resistance [1] In the industry, this type of hard alloys is a leader in the fracture of concrete, at the extraction of minerals in mining and processing of steel parts shock. The basis of most of the hard alloys is tungsten carbide. However, it has been found recently that cobalt and tungsten carbide particles have detrimental impact to health, and even have carcinogenic effect [2]. Therefore the development of alternatives to cobalt tungsten carbide is an actual problem. A new tool material should provide an increased level of flexural strength and toughness, thereby ought to be harmless for employees' health.

Fiber composites show high level of mechanical properties. It is rational to use super-deep penetration process (SDP) to create new fiber composite materials on the basis of cast steel billets. During SDP process powder particles

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work as needles and the fibers are formed in metal matrix under dynamic interaction between powder particles and matrix material [3].

Until now, a common understanding of process of particles penetration at SDP was not found what led many research groups continue working in this direction [4,5].

The phenomenon of interaction of cosmic dust particles (diameter less than 100 microns) with the spacecrafts observed in the near-Earth environment. The streams of cosmic dust are the constant factor of influence on space vehicles [6 - 8]. The process of super-deep penetration is used to determine the possible damages of spacecrafts with flows of cosmic dust and for control systems testing [9,10].

The aim of this paper is to study the possibility of creating tool composite materials and tools by volumetric alloying of cast steel billets.

2. Features of structure dynamic reconstruction at super-deep penetration

The qualitative difference between conventional powder metallurgy and creating composite materials by super-deep penetration effect is that great amount of discrete particles (powder) are considered as main physical tools. At SDP matrix is a massive material, steel with high initial strength.

Uniform pressure area occurs during a low velocity loading of solid metal body (static loading). At static loading conditions level of pressure $\leq 10^5$ N/m^2 is created. During normal blow in an open system the propagation of disturbance waves and shock waves are realized. The metal obstacles volume when impact process occurred is under pressure $\leq 10^9$ N / m^2 [3].

At SDP (dynamic loading) in a steel high pressure "solitons" occur - local regions of a pulsating high pressure (Fig. 1). High pressure zones are relatively stable and influence on steel forming “dark areas” of structure. Changing the structure of these areas is the result of dynamic phase transition.

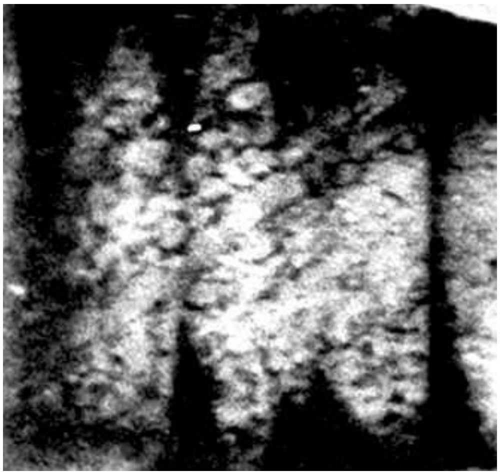

Fig. 1. Photo of high pressure "solitons" - zones of a pulsating high pressure, x6.

These pressure distribution features during SDP are particularly important for understanding the effects of SDP. Due to the high pressure gradient between the background pressure (light areas) and "solitons" (dark area) a complex pattern of shock waves redistribution is realized. It allows accumulating the impact of energy. Additional introduction of powder particles (less than 100 microns) in the steel barrier provides additional energy input and forms dynamic phase transition regions. In steel in "soliton" areas, dynamic phase transition is a relatively stable state during the interaction of flows of particles and the steel barrier. Zones, where the particles penetrated into a barrier to the depth of more than 2 diameters of the striker (particle), slams under the action of background pressure. These processes are realized only in a closed system (metallic matrix), i.e. removal of energy in real-time is drastically limited. During this period removal of energy from the closed system is possible only due to electromagnetic radiation. The energy level near the strikers reaches 10^{16} J/ m^3 [3].

3. Formation of steel composite structure

Traces of particle motion (tracks) are observed in areas with different pressure levels. The area of high pressure in a steel barrier at the SDP is an area of material with high level of structure defects. To prove this, a solid metal body after SDP was heated at 1000°C for 1 hour. After that the structure of high and low pressure areas was compared. In the structure of dark zone after heating grain refinement and occurrence of multiple recrystallization centers were observed. Grain growth in a dark zone (high pressure) started only after recrystallization. In the area of low-pressure (light area) grains of target material during heating process started to grow earlier than in a dark area. Red-hardness of steel after SDP increased significantly.

After SDP the fiber structures of residual defective material are occurred in the volume of solid metal body. These structures form a fiber carcass. The density of reinforcing elements in the longitudinal direction is usually in three times higher than in the transverse direction. Fibers are allocated in thin section in the form of tracks.

Hardness of the powder material has no effect on the penetration depth of particles in SDP mode. Introduced material forms fibers in the longitudinal and transverse directions relative to the axis of the collision of particles in steel target. This can explain the experimental results of alloying of steel bulks at SDP, i.e. in solid state.

Dynamic processing was carried out in the following conditions [11]: average particles speed 1000 m/s, exposure time ≈ 400 microseconds, material of billets: Steel 10 (0.07 – 0.14% C) or high-speed steel W6Mo5Cr4V2, material of strikers - various fractions of TiB_2 powders: 0-3 microns, 10-14 microns, 50-63 microns.

In the initial stage of the steel 10 (0.7 – 0.14% C) (Fig. 2) was used as a model starting material. Steel was processed with a high-speed bunch of TiB_2 powders of different factions. After treatment the mechanical properties changed. With increasing of particle size tensile strength dropped from 513 to 453 MPa and the tensile elongation increased by 6%. Maximum strength of steel 10 (0.07 – 0.14% C) was achieved with the introduction of TiB2 particles of 1 - 63 microns fraction. The strength increased by 15%.

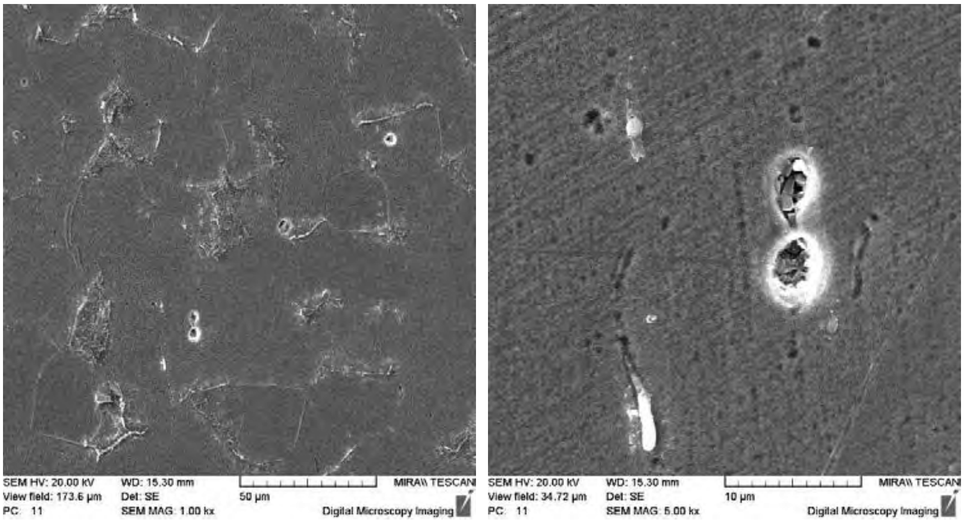

Fig. 2. Structure of steel 10 (0.07 – 0.14% C) after processing in the mode of super-deep penetration.

Notched samples were tested to study properties anisotropy of processed steel 10. Test samples were cut from the billets 45 and 40 mm in diameter, in a direction coinciding with the introduction of particles stream, and in the direction perpendicular to the introduced stream.

Maximum strengthening in steel 10 was observed near the surface of the billet. With the increase of depth, the tensile strength σ_t decreases. At depth of 19 mm tensile strength σ_t corresponds to the reference steel. With the increase of the fraction size of particles the depth of strengthening decreases.

The content of carbon in the initial steel affects its strength after processing. It was established that the maximum increase in the ultimate tensile strength (in comparison to the initial steel) was observed in steel with concentration of carbon up to 0.1%. With increase of carbon content in steel ultimate tensile strength decreases (steel with less than 0.2% of carbon), falling up to 0 (0.45% C steel), then slightly increases again (steel with more than 1% of carbon).

In this series of wear resistance of tool materials instrumental tungsten and molybdenum steels are the closest to hard alloys. Among these steels, sparingly alloyed high-speed steels widely spread for commercial purposes. Performed studies show the possibility of creation of fiber reinforced composite material in steel [12]. In the conditions of high-speed powder streams introduction ability of high-speed steels to reduce the tensions arising at penetration is sufficient to prevent the destruction.

Tool steel W6Mo5Cr4V2 was also put into research (Fig. 3). After quenching from temperature 1230 ° C and triple tempering at 560 ° C, this steel has a hardness 64HRCe, flexural strength $\sigma_{flex} = 323 \cdot 10^7 - 333 \cdot 10^7$ N/m^2 (3230-3330 MPa), annealed steel density $\rho = 8.1 \cdot 10^3$ kg/m^3. Tools made of this steel can be operated up to 600 ° C. Flexural strength and impact toughness of this steel are higher than in a hard alloy - WC + 8% Co. Therefore, to create a composite material which is capable to compete with such hard alloy is necessary to increase the wear resistance of the new composite.

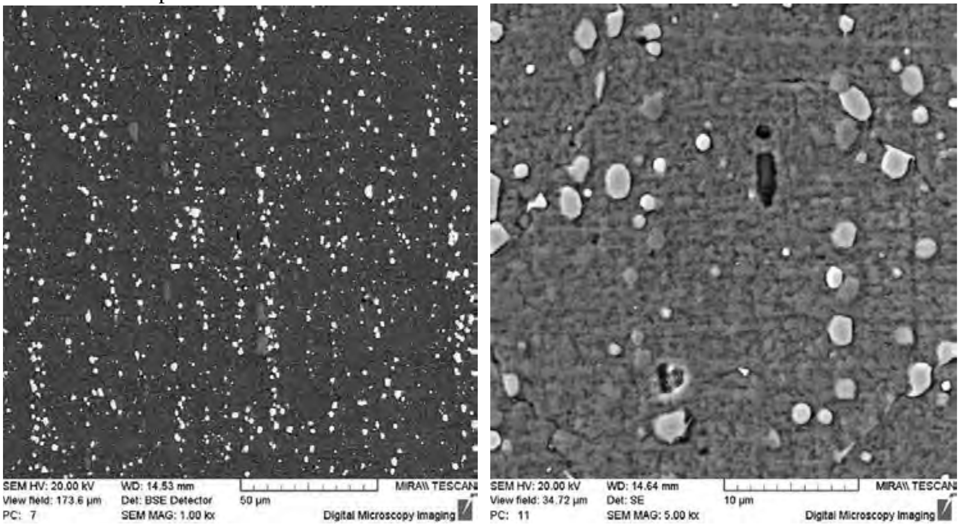

Fig. 3. Structure of W6Mo5Cr4V2 steel after SDP.

Experimental dependence of structure changes depending on the fraction size of introduced powder, and therefore changes of wear resistance, are shown in Fig. 4 and 5. An increase of share of fibers in the cross section reduces the weight loss during wear. Then, the influence of the fragility of the fiber zone increases. A further increase in the share of reinforcing fiber material reduces wear resistance of the tool material. For the material (steel W6Mo5Cr4V2) reinforced by TiB_2 particles with 1 - 63 microns fraction, the area of maximum wear resistance is in the range of 5 - 20% of the fibers in cross section.

Restructuring of tool steel due to its stitching by TiB_2 particles to a depth of tens and hundreds millimeters allows obtaining tool steel composite material with a specified level of properties. For farther tests techniques can be used at which weight loss of tool material happens in conditions of heavy wear and shock.

Processing steels with various powders in SDP mode allows synthesizing fibers of varied composition and, accordingly, with needed levels of properties [12]. Tests results (Figure 5) show that the volumetric reinforcement is achieved by changing powder compositions and fraction. Based on these conclusions technology for steel tool composite material creating has been made [13].

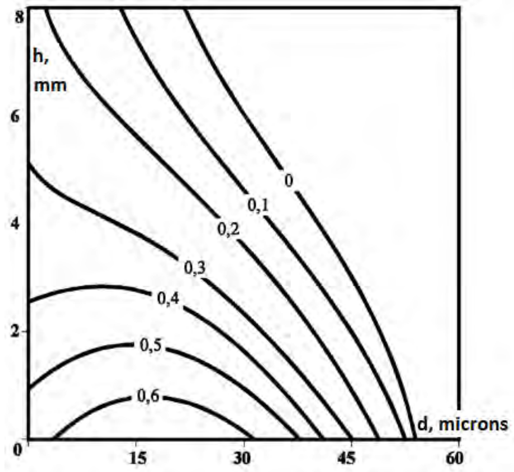

Fig. 4. Dependence of weight loss of W6Mo5Cr4V2 steel samples, reinforced by TiB_2 powder, from initial powder particles size and the depth of penetration ($\Delta P = f (d_p / h)$ g / $mm^2 \cdot m$.

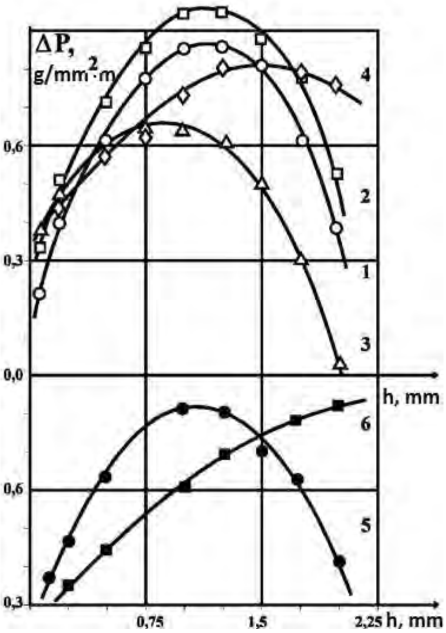

Fig. 5. Dependence of W6Mo5Cr4V2 steel samples weight loss on the distance to the surface: 1, 2, 3,4 -samples processed by 50-63 mm TiB_2 fraction , 5 - fraction 0-3 mm, 6 - fraction 10-14 mm.

A cycle of industrial tests of new instrumental composite steel was performed. The cutter body was reinforced by cutting cartridge made of composite steel. Mining machines were equipped with such tools in the amount of 6000 pieces and worked during a month. In equal conditions cutters from composite steel provide increased in 1.9 times operational tool life, energy consumption reduction in 1.2 times or at equal energy consumption they can increase the rate of tunneling up to 1.4 times. Thus, only during the tests it was additionally produced 1541.6 tons. It is important that all other energy costs, depreciation, etc. do not increase. Comfort operation of mining workers was increased. Thus, during the tests additionally 1541.6 tons of potash fertilizers were produced. It is important that all other cost – on energy, depreciation, etc. do not increase. Operation comfort of mining employees was increased.

Summary

1. Changing of the introduced powders composition allows realizing steels alloying in the solid state in a split second.
2. Operational tests of mining tools in conditions of simultaneous strike, wear and bending confirm the possibility of creation new materials for crushing, drilling and concrete processing instrument.
3. The obtained composite material based on high-speed steels can effectively replace currently used hard alloys based on tungsten carbide and cobalt. It is necessary to develop new schemes for tool steel composite production to use these materials in the manufacture of mining tools, drill picks, drills.

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