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PRODUCTION, STRUCTURE, PROPERTIES

Influence of Obtaining Conditions on Microstructure, Phase Composition and Properties of Eutectic Alloy of $WC-W_2C$ System

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Abstract—The influence of the obtaining conditions on microstructure, phase composition and properties of eutectic alloy of the $WC-W_2C$ system (relit), which is widely used as a surfacing material to strengthen the wearing parts, was installed. Using scanning electron microscopy, X-ray diffraction and durometric analyzes, it was found that the increase in mechanical properties is satisfactorily correlated with a decrease in the ratio between the number of phases of W_2C, WC and WC_{1-x}, the thickness of the phase layers in the grains, and the elongation of the latter.

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1. INTRODUCTION

Parts operating under high dynamic load, abrasive wear, in aggressive environments and at high temperatures, such as drills of oil and mining equipment, parts of metal cutting tools and others, have a service life of 3–5 times lower than other parts of these mechanisms. The worn out parts require replacement, which reduces the cost-effectiveness of production and increases the cost of repair. The problem of increasing wear resistance for Ukraine is also relevant due to the lack of dopants and the constant expansion of their application areas, for example, for extraction of shale gas. The problem of increasing wear resistance can be solved by manufacturing structural parts of machines and mechanisms from new materials with increased hardness, strength and fracture toughness or by modifying the surface of the traditionally used by applying wear resistant coatings [1, 2].

Ceramic materials have the highest values of melting point, the elastic modulus, the temperature of the beginning of intense creep, and hardness. Among the promising traditional materials for the wear protection of metal parts is the eutectic alloy of the $WC-W_2C$ system. The main disadvantage of ceramic materials is low strength and high brittleness. Of all the mechanisms of strengthening (decreasing grain size, fiber reinforcement, the plastic bonds introduction, the internal stresses creation, etc.) only reinforcement with monocrystalline fibers provides an increase in strength more than an order of magnitude. Obtaining of reinforced ceramic materials by mixing matrix–phase powders and fibers followed by sintering, hot pressing, isostatic pressing does not allow to maintain the integrity and uniform distribution of fibers in the matrix phase. Methods of crystallization from the eutectic alloys melts allow obtaining the regular arrangement of fibers and the formation of coherent and semi-coherent boundaries between the matrix phase and fibers, which is the main condition for increasing the structure thermal stability and improving the physical and mechanical properties of the material. At the same time, the degree of coherence, the uniformity of size distribution, the size of the fibers depends on the thermal conditions of crystallization, the chemical composition and nature of the phase components of the composite material [3, 4].

The main condition of the formation of reinforced ceramic materials by crystallization from the melts is the eutectic nature of the state diagram. It is known that the interaction between tungsten carbide and semicarbide is described by the eutectic state diagram, but the influence of the working conditions of crystallization on the microstructure and the phase composition of alloys of the $WC-W_2C$ system is not studied yet. Therefore, the study of the influence of the nature of the gaseous medium under crystallization on the microstructure, the phase composition and properties of the eutectic alloy of the $WC-W_2C$ system in order to increase mechanical strength and wear resistance is important.

The aim of the work is to determine the influence of the obtaining conditions on the microstructure, phase composition and properties of the eutectic alloy of the WC–W_2C system.

2. EXPERIMENT METHODOLOGY

Starting eutectic alloy of WC–W_2C tungsten carbides were obtained by centrifugal sputtering of castings smelted in a Tamman-type furnace at a temperature of 3100°C.

The pre-prepared electrode of the eutectic alloy of tungsten carbides, which is connected to the holder, was installed in a chamber filled with an inert gas (argon, nitrogen, or a mixture thereof). The toe of the rod was molded using a plasma arc discharge. Argon, nitrogen and argon–nitrogen mixture in the ratio of 50 : 50 were used as plasma-forming gas. The melt under centrifugal forces is removed from the end of the rod in the form of droplets and crystallizes in flight. During melting the rod is fed up. The surface of the chamber was cooled with water.

The microstructure of the resulting alloys was studied using a Mod. REM-106I scanning electron microscope (SELMI, Sumy, Ukraine).

Radiographic studies of the phase composition were conducted on a RIGAKU ULTIMA IV diffractometer using Rietveld and Reference Intensity Ratio (RIR) methods in radiation Cu$K\alpha_{1,2}$, $\lambda_{CuK\alpha1} = 0.1541$ nm.

The microhardness of an alloy was determined by the Vickers method with a PMT-3 microhardness meter at a load of 150 g on the diamond pyramid.

3. RESULTS

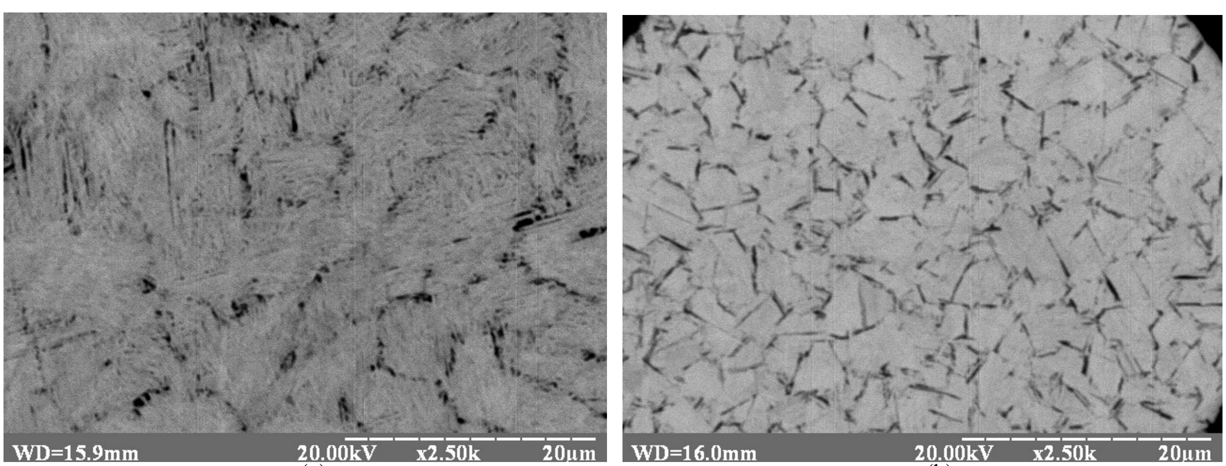
In order to confirm that the cooling rate leads to the formation of the cell structure [5], the microstructure of the eutectic alloy of the WC–W_2C system was investigated, depending on the working gaseous medium (protective and plasma-forming gas) and the size of the powder particles.

The eutectic alloy of WC–W_2C system have been obtained by centrifugal sputtering in the protective medium of argon (Figs. 1a, 1b, 1d) and nitrogen (Fig. 1c). As a plasma-forming gas, a mixture of nitrogen and argon gases was used in the ratio of 50 : 50 (Figs. 1a, 1c); nitrogen (Fig. 1b) and argon (Fig. 1d).

The Vickers hardness of the eutectic alloy of the WC–W_2C system, depending on the change in the protective and plasma-forming gaseous medium and powder dispersion, is significantly different (Fig. 2).

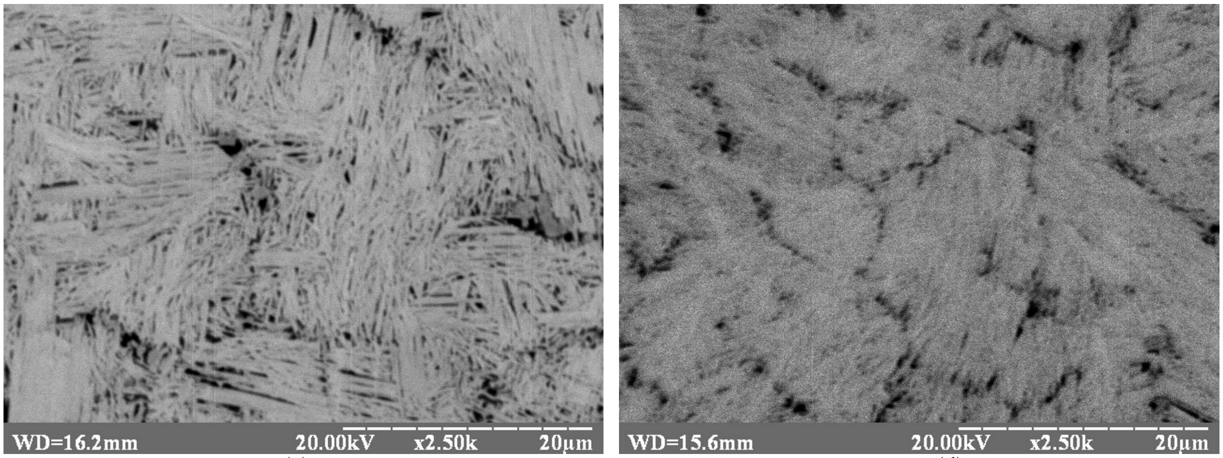
The X-ray phase analysis method identified three phases (W_2C, WC and WC_{1-x}) for alloys obtained in different gaseous mediums (Ar, N; Ar, N/Ar; N, N/Ar and Ar, Ar) and change their content was found (Fig. 3).

The content of the WC_{1-x} phase is 11 wt % in an alloy obtained in a protective argon medium heated by plasma from nitrogen, and in the alloy obtained in the protective medium of argon heated by plasma from argon, its amount is reduced by half, the content of the WC phase is practically not varying—18–20 wt %, the content of the W_2C phase varies from 69 to 78 wt %.



(a) (b)

Fig. 1. Microstructure of the eutectic alloy of the WC–W_2C system obtained in different gaseous mediums: a—Ar, N/Ar; b—Ar, N; c—N, N/Ar; d—Ar, Ar.



(c) (d)

Fig. 1. (Contd.)

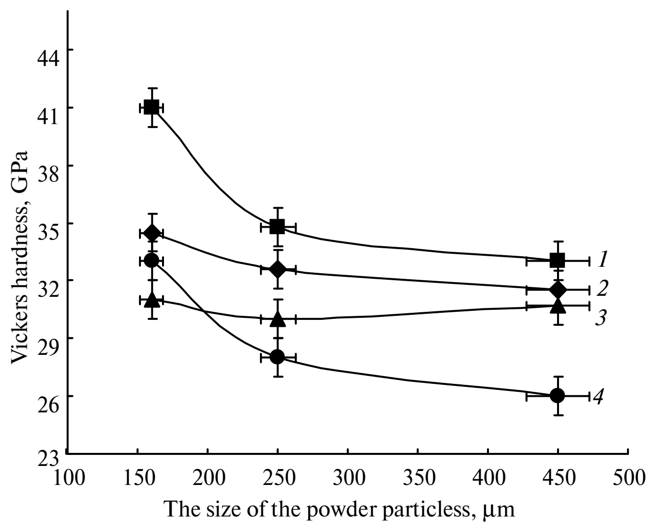


Fig. 2. Influence of the dispersion of a powder particles of eutectic alloy of the WC–W_2C system obtained by centrifugal sputtering in different gaseous mediums on hardness: Ar, N (*1*); Ar, N/Ar (*2*); N, N/Ar (*3*); Ar, Ar (*4*).

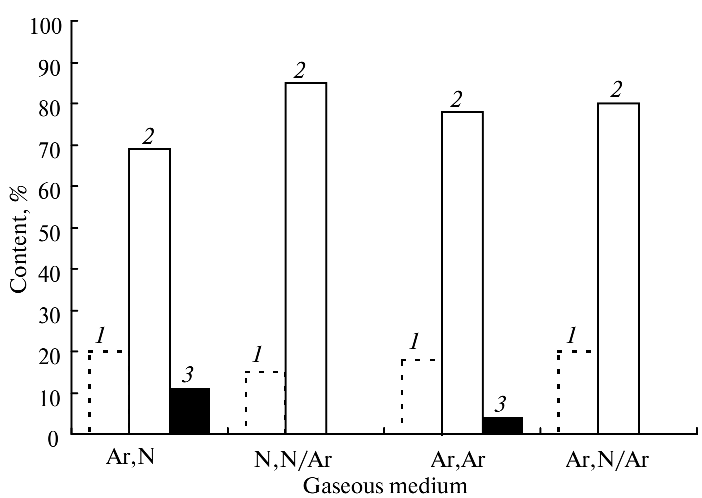


Fig. 3. Content of phase components of eutectic alloy of WC–W_2C system obtained in different gaseous mediums: WC (*1*), W_2C (*2*), WC_{1-x} (*3*).

4. DISCUSSION

The metallographic analysis found that the particles of the relit powders obtained by centrifugal sputtering had an almost perfect spherical shape in the size of 150–450 μm without visible defects on the surface and high density, and their microstructure was homogeneous and extremely fine crystalline due to the high cooling rate during crystallization in coating (see Fig. 1).

One can notice the difference only in the form of plates, the thickness of the layers of the phases in the beans and the elongation of the latter. The average length of the plates is 20–40 μm and the width is 0.5–2 μm (see Figs. 1a, 1b, 1d), and the length and width of the plates of the alloy obtained in the medium nitrogen–nitrogen/argon is 50–70 μm and 4–8 μm, respectively.

The highest values of hardness (41 GPa) are achieved on coatings from relit particles of a particle size less than 160 μm by spraying in argon the melt, heated by nitrogen plasma (Fig. 2). This is due to the main property of gases—the coefficient of thermal conductivity and the potential of ionization. The method of quantitative metallographic analysis has found that the increase of mechanical properties satisfactorily correlates with a decrease in the ratio between the number of phases of W_2C, WC and WC_{1-x}, the thickness of the phase layers in the grains and the elongation of the latter. The amount of W_2C decreases as the cooling rate increases, which leads to an increase in the hardness of coatings from smaller particles compared to coatings from larger ones.

It is established that during the sputtering in the nitrogen medium, the reduction of the hardness of coatings is due to the predominant carbon loss by the particles in the flight. Loss of carbon causes an increase in the amount and sizes of the W_2C phase, which leads to a decrease in hardness. Due to the higher thermal conductivity of nitrogen (2.57×10^{-2} W/(m·K)) compared with argon (1.71×10^{-2} W/(m·K)), the particles of a relit of the same diameter has greater hardness in the case of a higher cooling rate if the chemical composition (the ratio between the amount of tungsten and carbon) remains unchanged during spraying and crystallization.

As can be seen from Fig. 2, the Vickers hardness of the relit particles with increasing of the size of powder particles decreases, which can be explained by the formation of a more homogeneous fine crystalline structure due to the high cooling rate and the absence of visible surface defects.

5. CONCLUSIONS

The microstructure of the eutectic alloy of the WC–W_2C system, obtained in different gaseous medium, is significantly different. The smallest crystalline structure is observed in an alloy obtained in the protective medium of argon with a plasma-forming gas of nitrogen.

By means of X-ray diffraction and quantitative metallographic analysis it was found that the increase of mechanical properties is satisfactorily correlated with a decrease in the ratio between the number of WC and W_2C phases, the thickness of the phase layers in the grains, and their elongation.

It is shown that the hardness of the alloy increases by 1.5 times with an increase in the cooling rate, which satisfactorily agrees with reducing the size of grains and the change of the stress-deformed state of the phase components of the composite material and is explained by the mechanism of grain boundary strengthening.

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