

# Problems of Development and Application of Metal Matrix Composite Powders for Additive Technologies

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**Abstract.** The paper considers the problem of structure formation in composites with carbide phase and a metal binder under self-propagating high-temperature synthesis (SHS) of powder mixtures. The relation between metal binder content and their structure and wear resistance of coatings was studied. It has been shown that dispersion of the carbide phase and volume content of metal binder in the composite powders structure could be regulated purposefully for all of studied composites. It was found that the structure of surfaced coating was fully inherited of composite powders. Modification or coarsening of the structure at the expense of recrystallization or coagulation carbide phase during deposition and sputtering does not occur.

## 1. Introduction

An application of additive technologies to mechanical engineering has great prospects, because it allows significantly reduce of labor input at the manufacturing of complex shape parts while retaining the required quality. However, there are problems of powder feedstock materials for 3D-printing [1-2].

Along with the technological tasks related directly with the process of layerwise shaping articles, there is a problem of control and management of structure formed in this product, which should provide the necessary service properties.

In this regard the studies of interrelations of structural and phase states of composite powders and technological parameters of their preparation with subsequent application in surfacing processes are actual tasks.

The promising materials for additive technologies are metal matrix composite materials with fine carbide phase embedded to the binder [3-6]. In spite of numerous works devoted to carbide-containing powder materials [7, 8], a number of issues remains related to obtaining a predetermined composite structure: carbide particles of desired dispersity and volume content homogeneously distributed in the metal binder.

Results of structure studies of the composite powders “TiC – metal binder”, produced by self-propagating high temperature synthesis (SHS) in reactive powder blends of a wide range of inert metallic binder are presented in the paper. Structure and wear resistance of the coatings, overlaid by electron beam facing of the composite powders are presented too.

## 2. Materials and Experimental Procedures

Powders composed of disperse titanium carbide particles embedded into metal binder were obtained



by self-propagating high-temperature synthesis (SHS). Reactive powder mixtures of titanium (50-125  $\mu\text{m}$ ), carbon black ( $< 0.1 \mu\text{m}$ ), high-chromium cast iron or high-speed steel ( $< 125 \mu\text{m}$ ) were used.

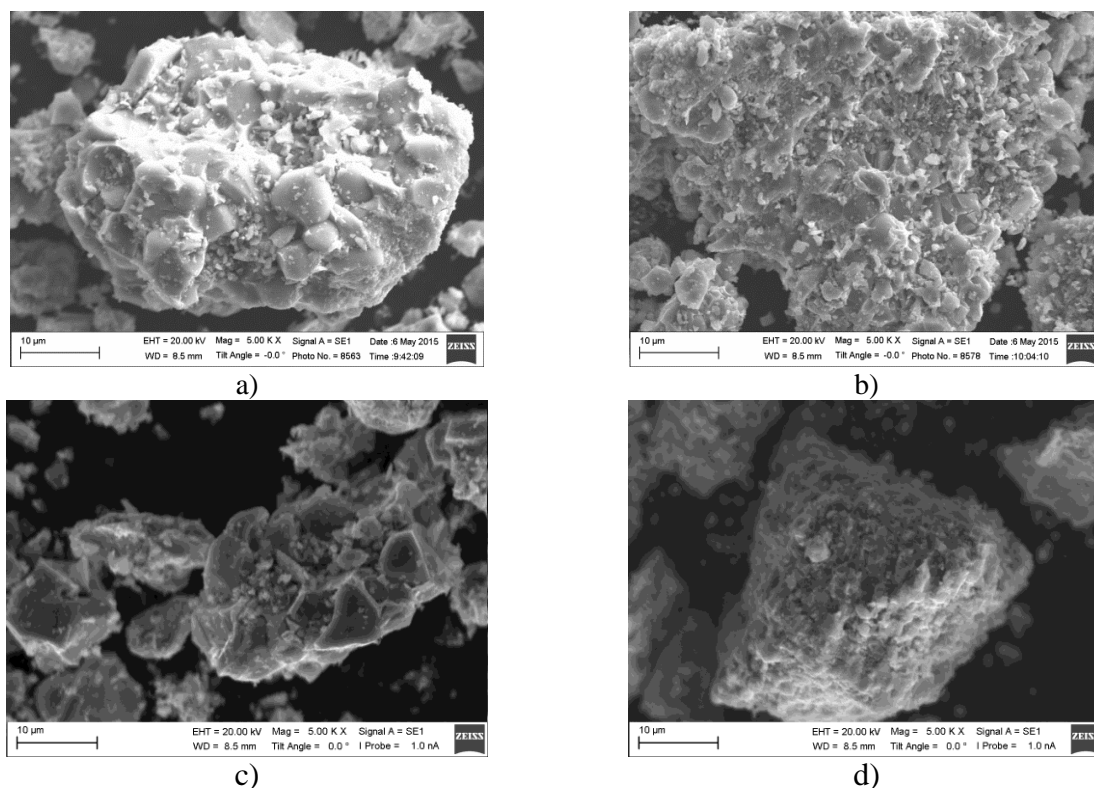
The contents of titanium and carbon in the reaction mixtures were calculated assuming the formation of equiatomic composition titanium carbide. A maximum content of thermally inert metal binder (cast iron, steel or titanium) was limited by the value at which the synthesis in layerwise combustion mode is possible. The mechanical activation of powder mixture has been used additionally for SHS ignition in the compositions with higher content of thermally inert binder.

Porous SHS-compact has been crushed and the necessary for coatings deposition fractions of the composite powder have been extracted by sieving. The synthesized composite powders were used for electron beam surfacing (EBS) and detonation spraying of wear-resistant coatings. Structure studies of SHS-composite powders and electron-beam coatings were carried out by using the equipment of the Centre of collective usage "NANOTECH" of the Institute of strength physics and materials science of Siberian branch of Russian Academy of Sciences (ISPMS SB RAS). AXIOVERT-200MAT metallographic microscope and "LEO EVO 50" scanning electron microscope were used for of SHS-powder morphology analysis, the microstructure of the SHS compacts and of the EBS coatings. The phase composition was determined by X-ray analysis (Co  $K_\alpha$ ). For phase identification and calculation of lattice parameters the ASTM X-ray data files and PDW in program were used.

### 3. Results

#### 3.1. Metal matrix composite powders

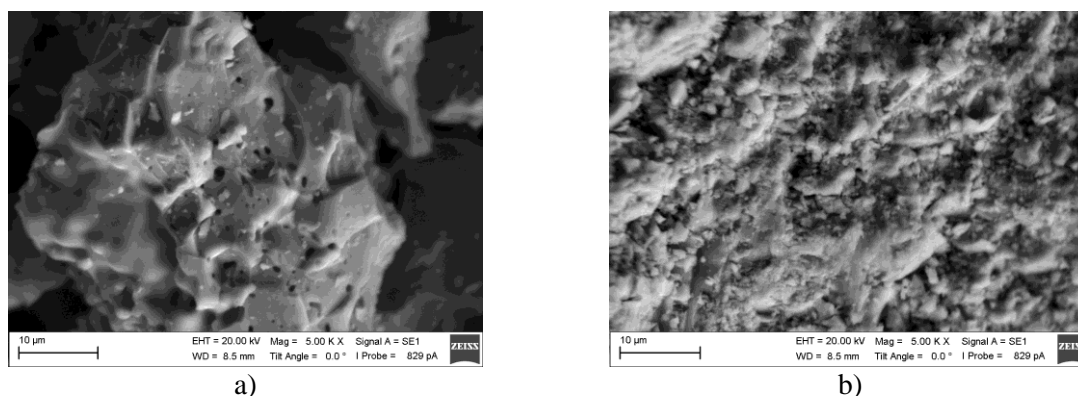
Carbides containing composite powders of investigated compositions with different volume content of metallic binder were obtained by crashing of SHS cakes. A representative morphology of the powders can be seen below (figure 1, 2).



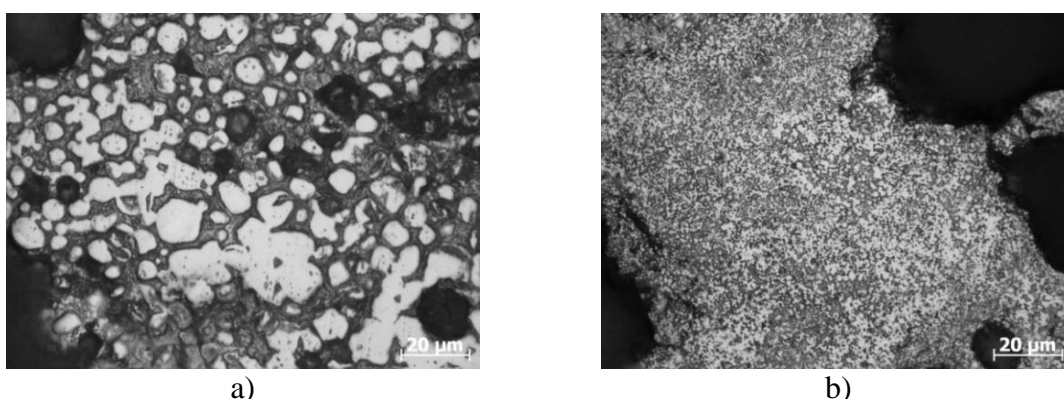
**Figure 1.** Morphology of SHS products with different contents of metallic binder (vol. %): high chrome cast iron - a) 22; b) 40; high speed steel - c) 20; d) 40.

At scanning electron microscope patterns (figure 1, 2) and cross sections of powder particles (figure 3) one can see, that SHS-composite powders consist of carbide inclusions surrounded by

interlayers of metallic binder. Regardless of the metal binder (cast iron, high speed steel or titanium) an increase of binder content in the reaction blends results in size reducing of the carbide inclusions in the composite structure (figures 1-3).



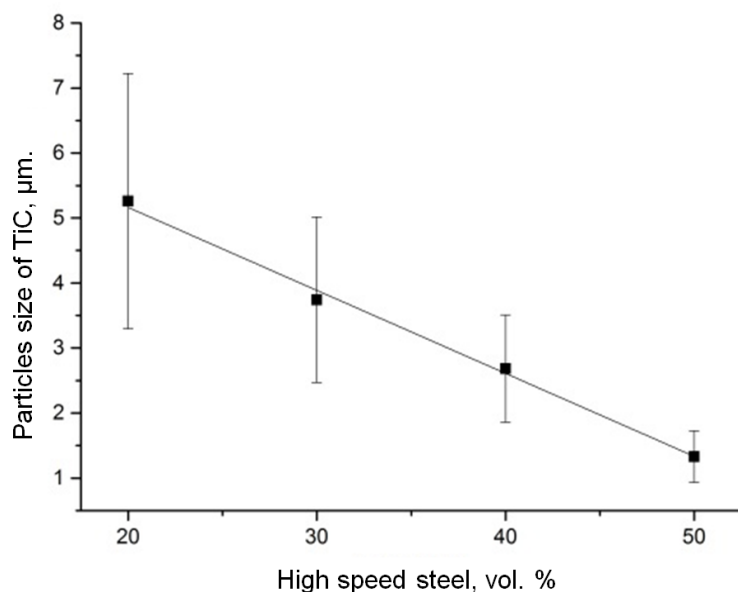
**Figure 2.** Morphology of “TiC – Ti” SHS products in Ti – C reactive mixtures with calculated / real contents of titanium binder (vol. %): a) 30 / 0; b) 60 / 24.6.



**Figure 3.** The microstructure of SHS composite powder “TiC – high speed steel” with binder content of (vol. %): a) 20; b) 50.

The greater is metal binder content in reactive blends, the less is size of the carbide inclusions. A typical relation “carbide size – metal binder content” presented at figure 4.

An average size of carbide particles in “TiC – high speed steel” composite powders decreases monotonically as the metal binder content in reactive mixes increases. The dependence of the average carbide particles size on metallic binder content in the composite structure can be explained by an influence of thermo-kinetic characteristics of the synthesis on the structure formation of composites [9]. With increasing content of the thermally inert metal binder the maximum combustion temperature decreases [7]. As a result, a temperature interval of the melt existence in a neighborhood of the reaction front becomes more narrow, and the time, during which the structure coarsening occurs by the growth of the carbide particles decreases.



**Figure 4.** The dependence of the average size of carbide inclusions in SHS composite powder “TiC – high speed steel” on volume content of metallic binder.

A possible deviation from the stoichiometry of the synthesized titanium carbide TiC should be taken into account in carbide-containing metal matrix composites. In particular, titanium binder content in the SHS composite powders “TiC – Ti” does not match with the calculated composition, when it is assumed the formation of equiatomic carbide composition. Owing to binder titanium transition to non-stoichiometric carbide a real binder content is much less than calculated one (Table 1). So in the TiC – 30 vol. % Ti composite the titanium binder is absent at all. Real metal binder content in the rest three composites is twice or more times less than calculated values with the assumption of equiatomic TiC formation (Table 1).

**Table 1.** The phases content in the “TiC – Ti” SHS products, the lattice parameter  $a$  of titanium carbide  $\text{TiC}_x$  and stoichiometry coefficient  $x$ , estimated from the lattice parameter.

The calculated content of phases in the SHS powders (with the assumption of equiatomic TiC formation)	The real phases content, %		$a$ , nm	$x$
	TiC $_x$	Ti		
TiC – 30 vol. % Ti	100	-	0.4320	0.71
TiC – 40 vol. % Ti	95.5	4.5	0.4310	0.58
TiC – 50 vol. % Ti	93.5	6.5	0.4302	< 0.53
TiC – 60 vol. % Ti	75.4	24.6	0.4299	< 0.53

The reason of binder deficit in “TiC – Ti” composites is a formation of non-stoichiometric titanium carbide at the SHS process. According to equilibrium binary diagram at the eutectic temperature titanium carbide with composition close to  $\text{TiC}_{0.5}$  is in equilibrium with  $\beta$ -Ti base solid solution. So the main portion of titanium from reaction mixture is consumed at the carbide formation.

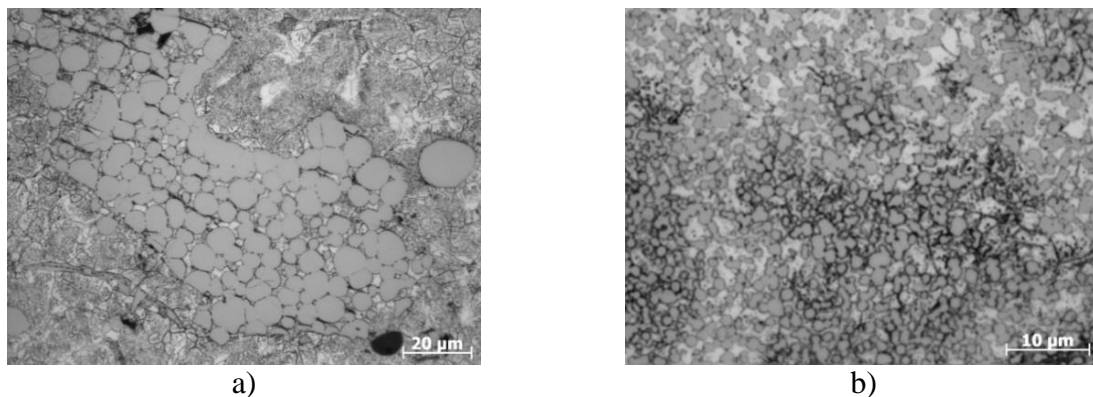
### 3.1. EBF coatings overlaid with the composite powders

SHS composite powders containing different metal binder (high chromium cast iron, high speed steel and titanium) were used for coating deposition by electron beam facing (EBF). For obtaining the

nonporous coatings the metal binder was added to the composite powders to get an integral 75-80 vol. % binder content in the coatings.

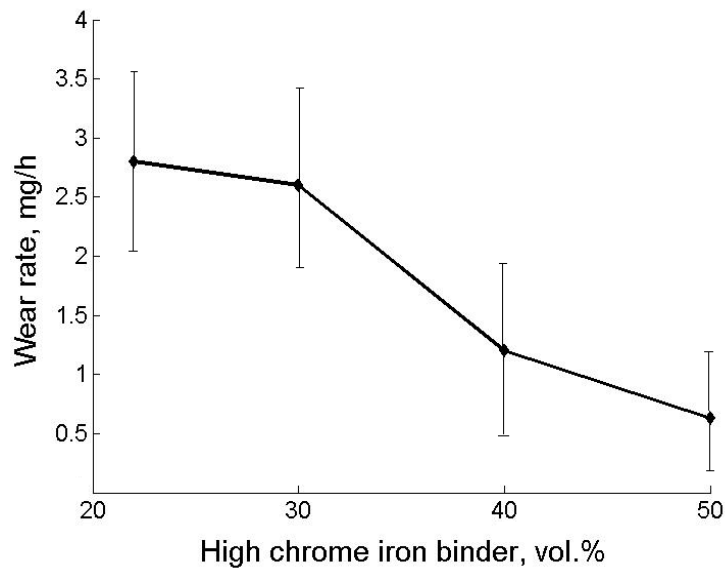
The microstructure of EBF coatings overlaid with “TiC – high speed steel” composite powder is presented on Figure 5. From a comparison of Figure 3 and Figure 5 it follows that dispersion of the carbide phase does not change at surfacing.

This means that the carbide phase recrystallization does not occur when surfacing as a result of dissolving the initial carbide in molten bath and subsequent primary carbide precipitation from the liquid solution under cooling. Thus, the coating structure can be purposefully controlled through the structure of the deposited powder.



**Figure 5.** Microstructure of EBF coating overlaid with “TiC – high speed steel” composite powders with volume content of steel binder (vol. %): a) 20; b) 50.

The coatings structure has a profound effect on the wear resistance. According to abrasive wear tests of the coatings overlaid with “TiC – high chrome cast iron” composite powders highest wear resistance has the coating overlaid with the powders of high content of metallic binder and low size carbide inclusions (Figure 6). High abrasive wear resistance of the coatings composed of fine carbide inclusions surrounded by narrow binder interlayers can be explained if abrasive wear mechanism is considered. The abrasive wear mechanism involves a deterioration of metal binder interlayers and following tearing away of the carbide particles. If a width of metal binder interlayers is comparable with abrasive grain size, wear rate is high. The narrower is binder interlayer the higher is abrasive resistance of the metal matrix composite. So the coatings with wide metal binder interlayers have a low abrasive wear resistance.



**Figure 6.** Dependence of electron beam coating wear rate on the binder content in the TiC – high chrome iron composite powders

### Summary

1. SHS in powder mixtures of titanium, carbon and thermally inert metals makes possible to obtain composite powders “TiC – metal binder” for deposition of wear-resistant coatings and for using in additive technologies. The elemental composition of the metallic binder can be maintained with good accuracy, because other carbide-forming metal powder components do not participate in the synthesis reaction due to high heat of TiC formation.
2. Dispersion, morphology and volume fraction of the carbide phase in SHS composite powders can be varied within a wide range due to a change of metallic binder content in reaction mixtures and by mechanical activation of the reaction mixtures.
3. A dispersity of the carbide inclusions remains invariable under electron beam surfacing of composite powders. So it is possible to obtain a predetermined structure of the deposited coatings.
4. The abrasive wear resistance of coatings deposited by electron beam facing with “TiC – metallic binder” composite powders depends on the volume content and dispersion of carbide phase, and is  $6 \div 35$  times higher than the wear resistance of VT1-0 titanium or high chromium cast iron.

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