SHS of “TiC – NiCrBSi binder” composite powders

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Abstract. Phase composition and structure of “TiC-NiCrBSi alloy binder” metal matrix composite powders have been investigated. The composites were synthesized from titanium, black carbon and Ni77Cr15Si3B2 alloy reaction powder mixtures by self-propagating high temperature synthesis (SHS). The composite powders were produced by crushing of SHS cakes. A size of TiC inclusions in NiCrSiB matrix depends on the content of NiCrBSi in the reactive powder mixtures and varies from 7.3 to 1.2 µm.

1. Introduction
Iron and nickel base water or nitrogen sprayed powders are widely used for sputtering and cladding of wear resistant coatings. NiCrBSi powders are the most often used. A wide use of the NiCrBSi powders is due to their excellent technological properties as applied to the coatings laying: good flowability in the powder feeders owing to spherical form of the particles, low melting temperature, high resistance to oxidation. On the other hand, sprayed and cladded coatings have a high hardness and wear resistance. In the majority of the published works laser cladding of NiCrBSi powders is used [1-4]. Plasma arc [5], gas-flame reflow [6] are less common used. High hardness and wear resistance of the coatings are provided by disperse particles of refractory compounds (borides, carbides and silicides) uniformly distributed in the metal matrix. However insufficient hardness and eagle-like shape of the inclusions limits a positive impact of the inclusions on the coatings properties. Therefore hard metallic carbides particles introduced into the powder mixtures are used to enhance wear resistance of NiCrBSi coatings. Tungsten carbide is most often used [7-9]. TaC [10], VC, Cr3C2 [11] are used too. Additional introduction of the metallic carbides into sputtered or cladded coatings results in considerable, sometimes many-fold wear resistance rise [10]. Titanium carbide seems to be the most promising as a strengthening phase in the coatings. Advantages of the titanium carbide under other metallic carbides are a maximum hardness and equal-axes shape of the inclusions. The most effective method to introduce TiC particles into metal matrix is self-propagating high temperature synthesis (SHS) in reactive powder mixtures of titanium, carbon and any metal or alloy resulting in the metal binder [12, 13].

In the present work phase composition and structure of “TiC – NiCrBSi alloy binder” metal matrix composite powders have been investigated. The composite powders were produced by crushing of SHS cakes. The cakes were synthesized from titanium, black carbon and Ni77Cr15Si3B2 alloy reaction powder mixtures.
2. Materials and experimental procedures

Reaction mixtures were prepared from titanium (99.5 %, <160 µm.), black carbon (average particles size 300 nm.) and Ni77Cr15Si3B2 (<100 µm.) powder mixtures. Ø 20×25 mm cylindrical samples were compacted from the mixtures to 35-38 % porosity. Composition of reaction mixtures and target values of NiCrBSi binder are given in Table 1. The titanium to carbon ratio in the reaction mixtures corresponded to equiatomic composition of titanium carbide.

| Table 1. Elemental composition of the reactive powder mixtures. |
|---------------------------------------------------------------|
| **Target content of Ni77Cr15Si3B2 metal binder in SHS products, vol %** | **Powder content, mass.%** |       |
| Ti | C | Ni77Cr15Si3B2 |
|---|---|----------------|
| 10 | 68.76 | 17.19 | 14.05 |
| 20 | 58.49 | 14.62 | 26.89 |
| 30 | 49.07 | 12.27 | 38.66 |
| 40 | 40.39 | 10.10 | 49.51 |
| 50 | 32.38 | 8.09  | 59.53 |

Synthesis was carried out in a sealed reactor at argon medium under 0.5 bar excess pressure. The combustion was initiated by heating of an igniting pellet by molybdenum wire coil. A resultant porous cakes were crashed and sieved to fractions of the composite powder granules.

Structure studies of the SHS products were carried out at the Centre of collective usage “NANOTECH” in the Institute of strength physics and materials science Siberian branch of Russian Academy of Sciences (ISPMS SB RAS) and National Research Tomsk State University (TSU) by X-ray diffraction (XRD-6000, CuKα), optical (AXIOVERT-200MAT, Carl Zeiss, Germany and scanning electron microscopy (LEO EVO 50, Carl Zeiss, Germany and Philips SEM 515).

3. Results and discussion

3.1. Phase composition of synthesized products

Synthesis in the powder mixtures presented in table 1 occurred in a stationary wave combustion mode. X-ray patterns of SHS powders are shown in figue 1, and the relative content of phases in the synthesized products, determined from the sum of the areas under the peaks of the individual phases listed in Table 2.

According to X-ray diffractometry basic phases in SHS products are a titanium carbide of non-stoichiometry, carbon deficit composition and nichrome (chromium – nickel solid solution). The total content of the strengthening phases (carbides, borides and silicides) does not exceed 8 %.

| Table 2. A relative phase content (%) of the SHS products. |
|----------------------------------------------------------|
| **No** | **Target composition, vol.%** | **TiC** | **Ni-base solid solution** | **Ni3B** | **(Cr,Fe)7C3** | **Ni3Si2** | **Ti** | **C** |
|---|-----------------|-------|-----------------|--------|----------------|------------|-------|-------|
| 1 | TiC + 20 % Ni77Cr15Si3B2 | 82.7 | 17.3 | – | – | – | – | – |
| 2 | TiC + 30 % Ni77Cr15Si3B2 | 70.4 | 24.0 | 1.9 | 3.7 | – | – | – |
| 3 | TiC + 40 % Ni77Cr15Si3B2 | 59.0 | 35.0 | 1.2 | 4.7 | – | – | – |
| 4 | TiC + 50 % Ni77Cr15Si3B2 | 46.5 | 39.3 | 2.9 | 5.1 | – | 3.1 | 3.1 |
| 5 | Ni77Cr15Si3B2 (As received) | – | 74.7 | 14.7 | 4.6 | 6.0 | – | – |

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3.2. Morphology and microstructure of the SHS powders

Powders received by crushing and sieving of the SHS cakes have a chip like form not depending on the carbide – binder ratio in the composite. However a microstructure of the composite powder granules considerably changes at increase of NiCrBSi content in the reactive powder mixtures (figure 2).

These microstructure changes are visible both on the granules surface (figure 2a, c, e, g) and on the granules cross-sections (figure 2b, d, f, h). The cross-sections were examined by optical microscopy on the samples embedded to resin. It is necessary to note a structure heterogeneity of the composites with the maximum content of the binder (figure 2h): binder areas with rare inclusions of separate carbide particles alternate with aggregations of the fine carbide particles. It was found by microstructure investigation of SHS products that an average size of the carbide inclusions in the metal binder falls monotonously as NiCrBSi powder content in reactive mixtures rises (figure 3). Dependence of this type is typical for reactions in the mixtures with thermally inert dopants [12–14]. The reason is a burning temperature drop (figure 4) by the alloy powder that is not involved in the reaction. It is known, that TiC inclusions size in the metal matrix composites is an important structure feature. It influence on hardness and wear resistance of the composites. Thus one can to get desirable properties of the coatings by using SHS composite powders of suitable structure for cladding or sputtering.

Figure 1. X-ray pattern of SHS products with different target volume content of metal binder.
Figure 2. An external view (a, c, d, e) and internal structure (b, d, f, h) of SHS granules with target binder content (vol.%): (a, b) – 20%; (c, d) – 30%; (e, f) – 40%; (g, h) – 50%.
TiC – NiCrBSi binder composite powders were synthesized in titanium, carbon and Ni77Cr15Si3B2 powder mixtures at the wave combustion mode. A size of TiC inclusions in NiCrSiB matrix depends on the content of NiCrBSi in the reactive powder mixtures and varies from 7.3 to 1.2 μm.

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