Solid State Contact Interaction Between Metal Matrix Composite Based on Ti64 with the Composite Based on B_4C

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Abstract: *The contact interaction between the metal matrix composite based on Ti64 and the B_4C-based composite was investigated. It is shown that the interaction process is influenced by the annealing temperature and holding time. The phase that formed independently of the contact pair is TiB. However, the thickness of the products formed at the boundary depends on the contact pair. In case of the Ti64-B_4C pair the thickness is 70 μm, while for (Ti64-40 wt% TiC)-B_4C it becomes 10 μm. This significant difference in the thickness is due to the presence of refractory particles (TiC) in (Ti64-40 wt% TiC)-B_4C couple, because the TiC phse reduce the diffusion of Ti into the contact zone.*
Keywords: CONTACT INTERACTION, METAL-MATRIX COMPOSITES, TITANIUM CARBIDE, TITANIUM BORIDE, MICROSTRUCTURE, BORON CARBIDE.

Introduction.

Titanium alloys are widely used in automotive, aerospace and advanced military applications because of their unique set of properties such as high specific weight, great strength and ductility, good corrosion resistance [1-2]. However, as technology evolves, homogeneous titanium materials may not always satisfy operating requirements. First of all, it is not possible to achieve a combination of high strength values without decreasing toughness and ductility of the material.

Boron carbide has a unique combination of high hardness (~32 GPa) and low density (2.5 g/cm^3) and attracts more and more attention every year. However, this material has one main disadvantages. It is the covalent type of chemical bond, resulting in a high melting point (2350°C, [3]) and a hot pressing (HP) temperature above 2100°C [4].The addition of the metal disiliside like $TiSi_2$, significantly decreases the temperature of densification to 1900°C [5]. On the other hand, the B_4C-$TiSi_2$ composite had the the highest mechanical properties than pure B_4C.

Our previous research [6] on the ***liquid phase*** interaction between Ti and B_4C showed multi-step mechanism of these reactions, which include solid state interaction with formation of TiB and TiC as well as further contact melting at the temperature close to the melting point of Ti. Because in the liquid phase interaction boron and carbon diffuse into titanium, and titanium does not diffuse into boron carbide, a weak and porous layer of TiB/TiC is formed.

The ***aim of this work*** was to investigate the contact interaction between MMC based on Ti and composite based on B_4C to find out the optimal regime for obtaining a dense and uniform connection between them

Materials and experimental procedure.

Hydrogenated titanium (TiH_2) powder (3.5 % H, wt.) and TiC was used as raw powder for obtaining MMC. The B_4C and $TiSi_2$ were used for fabrication ceramic composite.

Powder of hydrogenated titanium was blended with 60%Al-40%V master alloy powder (particles size < 63 μm) to form blend of total Ti-6Al-4V composition. Whenever inclusions of the second phase, such as TiC were needed to form MMC their powders were added at required amounts to the blends and mixed before the pressing. TiC powder with the size 1-30 μm was used to make MMC 40 % (vol.) of reinforcement particles. A smaller size samples, disk with dimension 40 mm and thickness 5 mm , at 150 and 640 MPa. Sintering of Ti-6Al-4V and Ti-6Al-4V-40% TiC was conducted in vacuum furnace (1250°C, 4h) followed by the slow furnace cooling. That provided dehydrogenation of titanium and formation of the bulk samples.

Powders of boron carbide were mixed with 30 vol. % $TiSi_2$ in a planetary mill in an acetone medium, using grinding beds with B_4C–20 vol % TiB_2. Disks with a diameter of 40 mm and a thickness of 6 mm were hot-pressed in a graphite mold, which was previously coated with boron nitride. Hot pressing was carried out at temperature 1900°C, pressure 32 MPa with holding time 30 min. After hot pressing, the materials were ground, polished, and finally treated with a diamond suspension with a grain size of ~1 μm.

The well-polished disk of MMC composite on the one side and B_4C composite with the other side, placed in the graphite die and heat to the temperature of 1500°C, under a pressure 32 MPa with holding time 15 min. The addition pressure was applied to create a strong contact between MMC and B_4C composite.

Microstructure of the samples was studies by scanning electron microscopy (SEM). Scanning electron microscopy was performed on VEGA 3 (Tescan). Local chemical compositions were determined by Energy-dispersive X-ray (EDX) spectroscopy with Oxford Instruments (UK) or Bruker (Germany) analyzers. Phase content was determined by areal analysis using image analysis software ImageJ. The grain size was estimated by the line intercept method, the data reported for each phase are the average of at least 100–150 grains using ImageJ software.

Results and discussion.

The microstructure of the as sintered materials are shown on the Fig.1. The Ti-6Al-4V had a homogeneous microstructure, Fig. 1 a. The addition of TiC into Ti-6Al-4V led to the formation of large particles TiC while the size of α-Ti and β-Ti remained unchanged, Fig. 1 b.

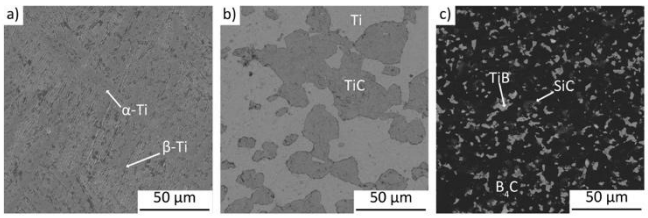

Fig.1. The microstructure of the initial materials: Ti-6Al-4V (a) and Ti-6Al-4V-40 vol% TiC (b) and B_4C-30 vol% $TiSi_2$ (c)

The microstructure of the hot pressed B_4C-30 vol% $TiSi_2$ are shown on the Fig. 1 c. As a result of the *in-situ* reaction between B_4C and $TiSi_2$, a final composite is formed with following phase composition: TiB, SiC and B_4C, Fig. 1 c. The introduction of an activating additive in B_4C is necessary, because the pure B_4C has a density of no more than 80% even at a temperature of hot pressing is 2100°C.

The cross section of the B_4C-30 vol% $TiSi_2$/ Ti-6Al-4V couple after annealing at 1500°C shown on the Fig.2.

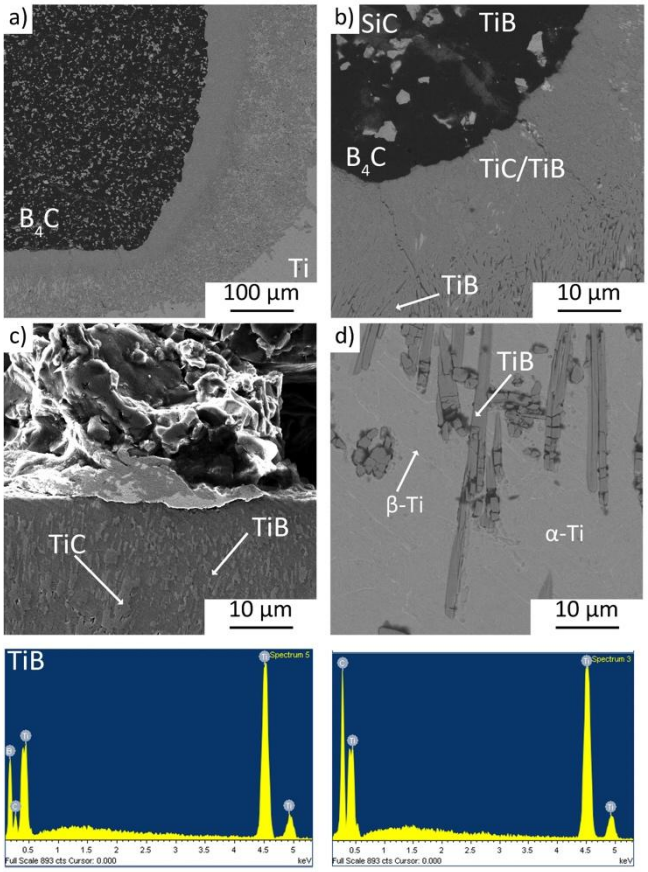

Fig.2. The cross section of the B_4C-30 vol% $TiSi_2$/ Ti-6Al-4V couple after annealing at 1500°C for 15 min: general view (a), general view at high magnification (b), microstructure at the grain boundary between B_4C-30 vol% $TiSi_2$/ Ti-6Al-4V (c), microstructure at the boundary between formed products and Ti-6Al-4V

The contact zone can be divided into several sections: first section is B_4C composite (Fig. 2 a), second section is the dense layer consisted from TiC and TiB phase (Fig. 2 b ,c), the third section of the TiB needle and α-Ti and β-Ti phase (Fig. 2 d), the last section is pure α-Ti and β-Ti. The thickness of the second section is 20-30 µm and has cracks. The crack was formed due to the mismatch between the ceramics and newly formed brittle region. The third section had the thickness of 100 µm and consisted from needle like crystal without trace of TiC.

These phases in section 2 and 3 were formed as a result of solid-phase interaction:

$3Ti+B_4C=2TiB_2+TiC$ (G1700=-588 kJ) (1)

$4Ti+B_4C=2TiB+TiB_2+TiC$ (G1700=-640 kJ) (2)

$4Ti+B_4C=3TiB+1/2TiB_2+1/2TiC+1/2C$ (G1700=-538kJ) (3)

$3Ti+B_4C=TiB+TiB_2+TiC+B$ (G1700=-494kJ) (4)

$4Ti+B_4C=4TiB+C$ (G1700=-534kJ) (5)

$2Ti+B_4C=2TiB2+C$ (G1700=-429kJ) (6)

$Ti+B_4C=TiC+4B$ (G1700=-106kJ) (7)

According to calculations, the most probable formation of titanium boride among all possible phases is, then titanium diboride and finally titanium carbide. Thus, at the initial stages, titanium boride is formed first as the most stable phase

The C has a lower diffusion coefficient than B and firstly formed TiC at the interaction region, Fig. 2 c. It should be noted that Yang [7] and Liang [8] using the differential thermal analysis in Ti-B_4C system observed exothermic effect with maximum at ~1093◦C. Therefore, the temperature of formation of TiC and TiB by contact interaction between B_4C and Ti are very close. Appreciably at the same time B react and formed TiB needle crystal. Since the amount of boron in boron carbide is 4 times higher than carbon, the number of needle like crystals is also significantly higher.

The cross section of the B_4C-30 vol% $TiSi_2$/ Ti-6Al-4V-40 vol%TiC couple after annealing at 1500°C shown on the Fig.3.Only a few zones can be observed. The first zone is adjacent to the boron carbide and consists of dense TiB layer. The thickness of this zone is 5 µm. Below this zone there is a thick layer of TiC. The thickness of this layer is 20 µm. It should be noted that TiC will play a role of a barrier.

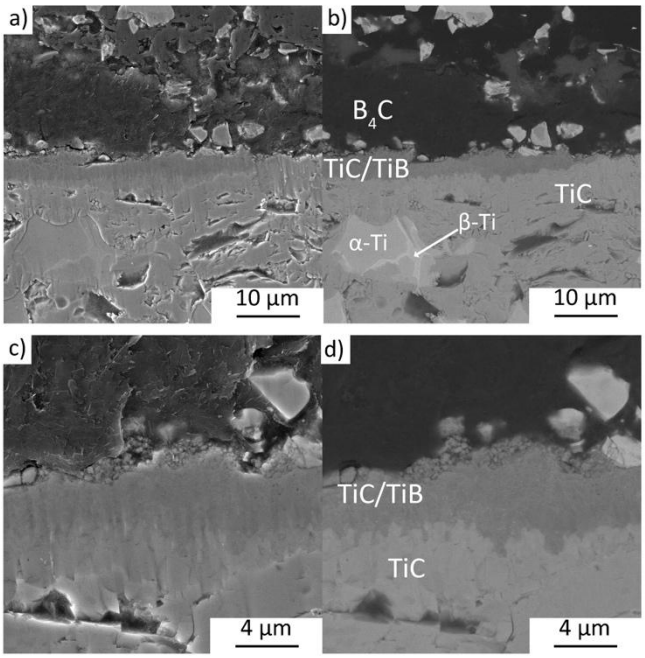

Fig.3. The cross section of the B_4C-30 vol% $TiSi_2$/ Ti-6Al-4V-40 vol%TiC couple after annealing at 1500°C for 15 min: general view (a,b), microstructure at the grain boundary between B_4C-30 vol% $TiSi_2$/ Ti-6Al-4V-40 vol%TiC (b,c); a,c-SE;b,d-BSE mode

Because the diffusion of B to TiC is significantly low as well as self-diffusion of C intro TiC. On the other hand, the reaction between B4C and TiC is not favorable, because the Gibbs free energy is +100 kJ/mol:

$B_4C + 4TiC = 4TiB + 5C$ (8)

The formation of a layer at the grain boundary between two materials by formation the new and danse phases increases the adhesion between them. Good adhesion between B_4 C and TiC brings several critical advantages, especially when they are used together in composite materials or multilayer structures. These advantages impact the mechanical, thermal, and chemical behavior of the material.

Conclusions

- During the interaction of B_4C-30 vol% $TiSi_2$/ Ti-6Al-4V, a two-stage interaction zone is formed. The total thickness of the interaction products becomes more than 150 µm. The first layer is two-phase and consists of TiB and TiC. The other layer consists of needle-like crystals of TiB that permeate the Ti matrix.
- Addition of TiC to Ti-6Al-4V significantly reduces the thickness of the interaction region to 20 µm by reducing the diffusion of B and C into the interaction region.
- The formation of layers at the boundaries between composites by co-annealing can be used to obtain layered materials.

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