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A comparative study of borided pure niobium, tungsten and chromium

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Abstract

Pure niobium (Nb), tungsten (W) and chromium (Cr) were boronized at 940 °C for 2, 4 and 8 h. The borided samples were characterized by X-ray diffraction, Scanning electron microscope and microhardness tests. Tribological investigation was conducted. X-ray study showed the presence of NbB_2, WB, and CrB. The hardnesses of boride layers formed on the pure Nb, W and Cr were 2500, 2500 and 1700 HV, respectively, whereas the hardnesses of the pure Nb, pure W and pure Cr were 110, 445 and 115 HV, respectively. Nb boride layers ranged in thickness from 8 to 22 μm, whereas W boride layers ranged in thickness from 10 to 42 μm, and the thickness of Cr boride layer varied from 4 to 12 μm with boronizing time. The boriding of W resulted in thicker boride layer compared to the boriding of Nb and Cr at given time. The frictional behaviour and wear mechanicms differ in modes and scales.

Keywords: Borides; Boronizing; Niobium; Tungsten; Chromium

1. Introduction

Refractory metals such as cobalt–chromium (Co–Cr) alloys, tantalum (Ta), niobium (Nb) and titanium (Ti) have been used for implantation since they have excellent corrosion resistance [1]. Ta and Nb show better electrochemical properties and at least equally good biocompatibility compared to other established implant materials, but lower mechanical strength than Ti and its alloys [2,3]. The mechanical properties of Ta and Nb may be improved by cold working. Alloying may increase the strength more effectively, however, it might negatively influence the biocompatibility of the implants due to release of alloying elements [4]. Coating with certain compounds is one way of improving the mechanical properties of materials such as hardness. Therefore, the hardness of Nb, W and Cr can be increased by coating techniques. One of the coating techniques is boronizing, a thermochemical diffusional surface treatment in which boron atoms diffuse into the surface of the work piece to form hard borides with the base materials [5–11]. Boronizing is a prominent choice for a wide range of tribological applications where the control of friction and wear is of primary concern [12]. The strong covalent bonding in most transition metal diborides is largely responsible for their high melting points, high mechanical strength, elastic moduli, hardness values and chemical inertness [12,13]. The research that investigated a wear mechanism of the borided pure W for biological applications was reported in the literature [14]. Although the characterization of borided pure Nb and W are present in literature [15,16], the comparative study of borided Nb, W and Cr will be usefull to understand the boriding of refractory pure elements.The present paper reports on a study performed at 940 °C for 2, 4, and 8 h for the boronizing of pure Nb, pure W and pure Cr in solid boron medium. The primary purpose of this study is to examine some mechanical properties of the boride formed on the surface of the pure Nb, the pure W and the pure Cr.

2. Experimental procedure

Substrate materials were 99.8 wt% Nb, 99.95 wt% W and 99.98 wt% Cr. Boronizing was performed in a solid medium by using Ekabor powders that had grain sizes of

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less than 850 μm and had a nominal chemical composition of 90% SiC, 5% B_4C and 5% KBF_4. The test materials to be boronized were placed in contact with Ekabor powders and then transferred to an electrical resistance furnace in a stainless-steel crucible of 5 cm in diameter and 8 cm in height. The test materials were heated to a temperature of 940 °C under atmospheric pressure and held in the furnace for 2, 4, and 8 h. This was followed by cooling in air. The morphology and types of borides formed on the surface of Nb, W, and Cr substrates were examined by means of conventional metallographic technique. Rigaku X-ray diffractometer was employed for the characterization of the borides. Philips field emission scanning electron microscope (FE-SEM) was used to study the morphology of the borides. The microhardness of borides formed on the surface of the samples and hardness of the borides from the surface to the interior of the base materials were measured by Instron microhardness tester with a load of 50 g (0.49 N) for Nb samples, 100 g (0.98 N) for W samples and 50 g (0.49 N) for Cr samples for 10 s. Before the measurements, samples were prepared according to metallographic techniques. The depth of boride layer was determined by a digital measurement instrument (Olympus OSM-DC) attached to an Olympus BHM-313 optical microscope. Tribological performance was studied for the borided specimens (boronized for 4 h). Friction and wear experiments for borided Nb, W and Cr were carried out using a reciprocal pin-on-disc tribometer (CETR UMT and CSM). The detailed procedure is mentioned elsewhere [14,17,18]. The bottom part sample disk is movable and the top pin or ball stays stationary. The disks are flat surfaces of borided Nb, W, and Cr. The pins and balls are bearing steel balls with diameter of 6 mm for each test. The sample surfaces were first cleaned using an ultrasonic cleaner in acetone for 10 min to remove physically bonded foreign particles and dust. The friction and wear tests were performed for 300–3600 s at an applied load of 5 N. The wear track legth was 4 mm. The wear mechanisms were investigated using surface characterization techniques. The fine scale analysis of wear mechanisms was conducted using an atomic force microscope (AFM). The scanning probe was made of silicon. The contact mode of AFM operation was applied.

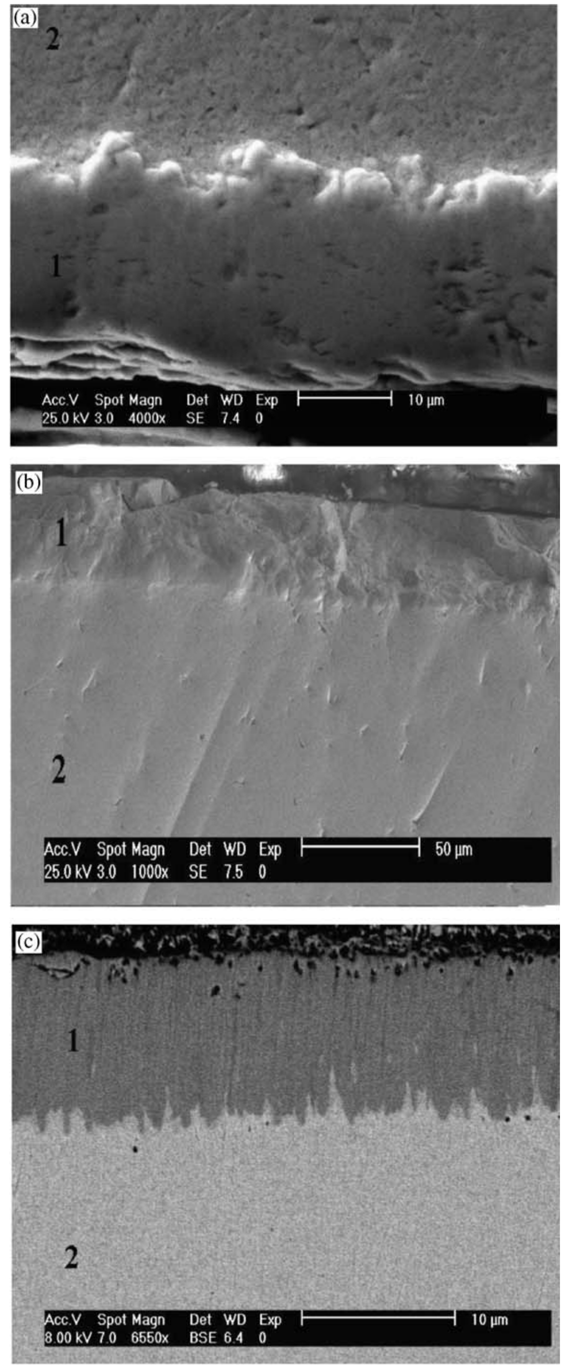

Fig. 1. (a–c) SEM images of borided Nb, W and Cr at 940 °C for 8 h, showing two distinct regions: (1) a layer having borides (NbB_2, WB and CrB) and (2) a base material, which is not affected by boron.

3. Results

3.1. Microstructure

SEM examinations of borided Nb, W and Cr reveal a nearly compact and smooth morphology boride coating. Fig. 1(a–c) shows SEM examinations of the borides formed on the Nb, W and Cr substrates borided at 940 °C for 8 h. Two regions appear in Fig. 1(a–c): (1) a layer having boride NbB_2 for Nb, WB for W, and CrB for Cr and (2) a base material, which is not affected by boron. It will be possible to observe the other region between both. This will be discussed in next section.

3.2. Hardness, boride layer thickness and characterization

The hardness measurements were performed on boride layer, on layer just below the boride layer, and on base materials depicted as 1, 2 and 3 shown in Fig. 2(a–c), respectively. The hardness of boride layer (1) on Nb is 2500 HV, whereas the hardness of region (2) and substrate (3) are 670 and 110 HV, respectively. Meantime, the hardness of the boride (1) on W was 2500 HV, while the