Corrosion resistance enhancement of WC-Co hardmetal in NaOH solution.

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1. Introduction

SiC is a useful non-oxide ceramic material having unique physicochemical and mechanical properties such as high strength, excellent wear, and oxidation and corrosion resistance [1-3]. These properties originate from the very strong covalent bond between silicon and carbon and its tetrahedral coordination. However, adhesion between the materials is a serious obstacle to the application of a SiC coating to WC-Co. Several techniques are used to improve the adhesion, such as sputtering, ion beam mixing (IBM), dynamic ion mixing and ion beam assisted deposition. Among those, IBM is a powerful tool [4,5]. This paper demonstrates that SiC can be successfully coated on WC-Co through the IBM technique. The corrosion resistance of WC-Co in alkali solutions is greatly enhanced by the ion mixed SiC coating, as proven by potentiodynamic electrochemical experiments.

2. Methods and Results

2.1 *Ion beam mixing*

The SiC coating was prepared an IBM technique in conjunction with an electron beam evaporator. All substrates (high purity WC-Co) were cleaned with ethanol using an ultrasonic cleaner and, then, mounted on the sample holder in the chamber that has two perpendicular rotation axes. For the IBM technique, an important factor is the initial deposition thickness at which the irradiated ion beam most effectively activated the boundary between the deposited material and the substrate material. This initial deposition thickness was calculated by the stopping and range of ions in matter (SRIM) code. Note that the initial deposition thickness for SiC coating was about 100 nm. After the initial deposition, the samples were faced in the direction of ion bombardment by rotating them by about 90°. In this experiment, nitrogen ions were irradiated with irradiation energy of 70 keV and ion dose of ~1 × 10^{17} particles/cm^2. Then, the additional deposition was performed by the electron beam evaporator until a desired thickness was obtained. The base pressure of the chamber, which was evacuated by a turbo molecular pump and a rotary pump, was about 10^{-6} Torr while an operating vacuum was below 5 × 10^{-5} Torr. N^+ and N_2^+ ions were produced by the DuoPIGatron ion source in a 2:8 ratio, and an X-Y recorder was used in conjunction with a Faraday cage to obtain an accurate ion dose. During SiC deposition, the samples were rotated at 8.5 rpm, which guaranteed homogeneous deposition. The deposition was conducted by the electron beam evaporator at a coating rate of ~ 1 Å/sec produced by an electron beam current of ~ 0.15 A. The substrate temperature during the electron beam deposition is about 150 ℃. A calibrated quartz crystal oscillator (STM-100/MF, Sycon Instruments Inc) was used to control the growth rate and coating thickness.

2.2 corrosion test

The working electrode (rectangular coupon 20 mm × 20 mm) was prepared from WC-Co or SiC-coated WC-Co that was connected to a Cu lead wire. A saturated calomel electrode (SCE) and a Pt wire were used as the reference and counter electrodes, respectively. A potentiodynamic test was performed for the WC-Co and SiC-coated WC-Co samples from -1.5 to +1.0 V(SCE) at a scan rate of 1 mV/sec in 1M NaOH solutions by using a potentiostat/galvanostat (EG&G 273A). All the polarization tests were performed in an electrochemical cell at room temperatures. Before the polarization test, the electrochemical test system was stabilized in the test solution for 30 min.

2.3 Results

Fig.1 (a) displays the potentiodynamic curves for two samples in 1M NaOH solution, whose pH is 14. The dashed and solid lines are the potentiodynamic curves for the as-received and SiC-coated WC-Co, respectively. The potentiodynamic curve for the as-received WC-Co shows a critical current of around -0.5 V(SCE), indicative of an active to passive transition, and displays a steep current increase around 0 V (SCE), due to the breaking of the passive layer and/or the oxygen evolution reaction. The passive layer consists of a Co-hydroxide layer and a WO_3 layer, etc [6-9]. The potentiodynamic curve for the SiC-coated WC-Co is shifted leftward and upward, compared to that for the as-received WC-Co, suggesting that the corrosion resistance is increased by the SiC coating. For the SiC-coated WC-Co, neither the passive region nor the active-passive transition is clearly observed. The corrosion potential (E_{corr}) for the SiC-coated WC-Co is about -0.49 V(SCE) whereas E_{corr} for the as-received specimen is -0.83 V(SCE). The corrosion current densities obtained by the polarization resistance method are 1.1 × 10^{-4} A/cm^2 and 8.2 × 10^{-6} A/cm^2 for the as-received WC-Co and the SiC-coated WC-Co, respectively.

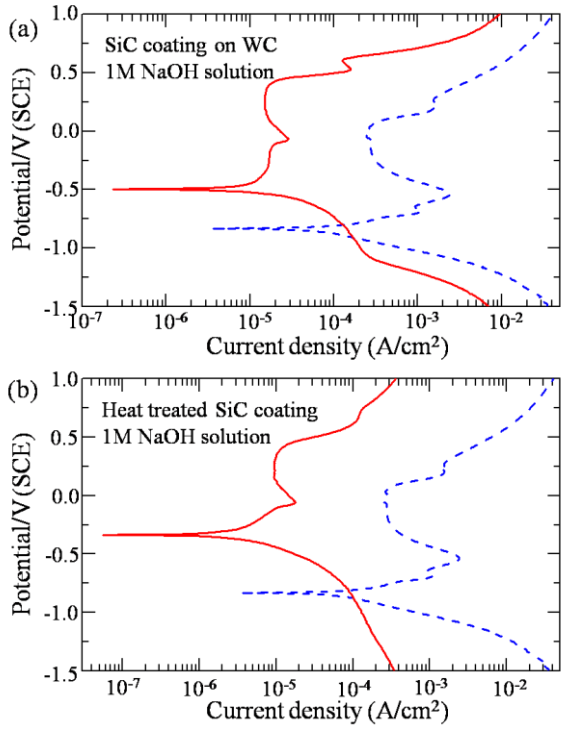

Fig. 1. The potentiondyamic polarization curves in the 1M NaOH (pH = 14) (a) for the SiC coating on a WC-Co and (b) for the heat treated SiC coating on a WC-Co.

Generally, heat treatment at the proper temperature can make an adhesive coating and improve the quality of the coating by the thermal diffusion [10]. Thus, heat treatment can improve the corrosion properties of the coating. However, heat treatment in air oxidizes WC-Co, degrading its corrosion properties. Thus, a vacuum is essential to successful heat treatment. Heat treatment was performed at 500 ℃ for 10 hr. Fig. 1 (b) compares the potentiodynamic curves for the as-received WC-Co hardmetal (dashed line) and the SiC-coated WC-Co with heat treatment (solid line). Again, the potentiodynamic curve for the SiC-coated WC-Co with heat treatment is similar to that for the as-received WC-Co. However, the corrosion current density of the SiC-coated WC-Co with heat treatment is about 50 times less than that of the as-received WC-Co. Thus, the SiC-coated WC-Co with heat treatment dramatically improves the corrosion properties in NaOH solution which is a representative strong alkaline solution.

3. Conclusions

This study investigated the corrosion properties of the SiC coated WC-Co in the 1M NaOH (pH =14) solution. Among all the specimens, the best corrosion properties are displayed by the SiC coating with the heat treatment at 500 ℃ whose corrosion current density and corrosion rate are dramatically reduced in the 1M NaOH solution compared to the WC-Co.

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