Improvement of Hardness and Wear Resistance of (TiC, TiB)/Ti-6Al-4V Surface-Alloyed Materials Fabricated by High-Energy Electron-Beam Irradiation

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The objective of this study is to investigate microstructure, hardness, and wear properties of three kinds of (TiC, TiB)/Ti-6Al-4V surface-alloyed materials fabricated by high-energy electron-beam irradiation. The mixtures of Ti + C, TiC + TiB₂, and Ti + B₄C powders and CaF₂ flux were deposited on a Ti-6Al-4V substrate, and then high-energy electron beam was irradiated on these mixtures. The surface-alloyed layers of 0.9 to 1.6 mm in thickness were homogeneously formed, and contained a large amount (30 to 44 vol. pct) of hard precipitates such as TiC and TiB in the martensitic matrix. This microstructural modification improved the hardness and wear resistance of the surface-alloyed layer 2 times and 6 to 9 times, respectively, greater than that of the substrate. Particularly, the surface-alloyed material fabricated with Ti + B₄C powders had a larger volume fraction of TiB and TiC homogeneously distributed in the martensitic matrix, and thus showed the best hardness and wear resistance. These findings suggested that the surface-alloying using high-energy electron-beam irradiation was economical and useful for the development of titanium-base surface-alloyed materials with improved hardness and wear properties.

I. INTRODUCTION

THE Ti-6Al-4V alloys have many attractive properties such as high specific strength, stiffness, and excellent corrosion resistance that have made them attractive for use in structural and engine parts of ultrasonic airplanes, materials for petrochemical plants, and surgical implants. However, their poor resistance to wear at room temperature and oxidation at high temperatures have required surface treatments. Thus, studies on the development of new advanced materials whose surface properties are enhanced have been conducted to achieve surface hardening or surface alloying.

Surface alloying is a method for forming an alloyed layer on a substrate to improve the resistance to corrosion, wear, and heat. Recently, this has been developed by direct irradiation using high-energy heat sources such as pulsed laser or electron beam. The laser beam method requires absorption materials to increase the absorption ratio, and has overlapping problems when a large surface area needs to be treated. The conventional electron-beam method has been mainly applied to welding of relatively small parts because it requires a vacuum chamber. However, the high-energy (several MeV energy range) electron-beam irradiation method can be continuously performed in air, and thus can treat a very large area at one time, which makes it advantageous for the fabrication of large structures or parts. Compared with the laser beam method, this method has 2 times higher thermal efficiency and produces a thicker surface-alloyed layer of several millimeters in thickness due to penetration depth.

Upon irradiating the metal surface with high-energy electron beam, high kinetic energy of electrons, being struck into the material lattices and forming phonons, is transformed to thermal energy, which can easily melt ceramics. When the metal substrate, on which ceramic powders are evenly deposited, is irradiated with electron beam, both ceramic powders and the substrate surface are melted. In this process, ceramic elements are dispersed and infiltrated into the substrate, thereby fabricating ceramic/metal surface-alloyed materials. This electron-beam irradiation method rarely forms pores or cracks because of high thermal efficiency and homogeneous heating and cooling.

In this study, a simple process was suggested to fabricate (TiC, TiB)/Ti-6Al-4V surface-alloyed materials by evenly depositing ceramic powders such as TiC, TiB₂, and B₄C powders on a Ti-6Al-4V alloy substrate and then irradiating with a high-energy electron beam. Flux had to be used to protect these powders from reacting with air and to promote homogeneous melting. Three kinds of surface-alloyed materials were fabricated by varying ceramic powders, and their microstructure, hardness, and wear properties were comparatively analyzed to understand the mechanisms of surface alloying and property improvement.

II. EXPERIMENTAL

A Ti-6Al-4V alloy (ASTM-B-265, grade 5) obtained from OREMET Co. (Albany, OR), was used as a substrate, and its chemical composition is Ti-6.27Al-3.82V-0.17Fe-0.17O-0.01C-0.01N-0.006H (wt. pct). Figure 1(a) is an optical micrograph of this substrate, which consists of equiaxed α and intergranular β phases. Ceramics used for surface alloying are TiC, TiB₂, and B₄C powders having high hardness,
microscope and scanning electron microscope (SEM). Phases present inside the surface-alloyed layer were analyzed by X-ray diffraction and energy dispersive spectroscopy (EDS), and their volume fractions were measured by an image analyzer. Hardness was measured from the surface down to the substrate by a Vickers hardness tester under a 500-g load, and microhardness of matrix and precipitates was measured by an ultra-micro-Vickers hardness tester under a 25-g load.