Improving the Tribological Behavior of Commercially Pure Titanium Using TIG Surface Alloying

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Abstract

Titanium alloys are widely applied to marine, biomaterials, chemical, petrochemical and automotive industries because of their unique property such as excellent creep resistance, corrosion resistance and relative higher specific strength ratio. However, they suffer from poor tribological properties such as low surface hardness and absolute values of tensile and shear strength which result in low wear resistance. On the other hand when Ti alloys are worn, they produce a dark-colored dust which is not environmental friendly. This project is aimed at producing hard and wear resistant particles in a matrix of Commercially Pure Titanium (CP-Ti) substrate by TIG (Tungsten Inert Gas) surface alloying. Different mixtures of Molybdenum and Titanium Carbide powders were applied to the surface in order to improve the hardness of surface layers. The microstructure of TIG alloyed layers were analyzed by OM, SEM and E-DAX. It was found that the hardness of the treated layers was more than three times higher than that of the CP-Ti substrate. Moreover, the wear resistance of this coatings were between 60 to150 times better than the base material.

Keywords: CP Titanium, Surface Alloying, Molybdenum, Titanium Carbide, Wear Resistance.

1. Introduction

Titanium based alloys are well known by their remarkable combination of high specific strength and good oxidation resistance, which make them useful for high-temperature applications up to a temperature of 450ºC [1,2]. However, their poor tribological properties such as low abrasive wear resistance, poor fretting behavior and high coefficient of friction have restricted their utilization in many sliding parts, tools and components which are prone to wear[3,4]. Their law wear resistance is mainly attributed to the high surface friction and the low surface hardness of these alloys. On the other hand, when Ti alloys are worn, they produce a dark-colored dust which would impact the environment. Titanium dust inhalation may cause tightness and pain in chest, coughing, and difficulty in breathing. Contact with skin or eyes may cause irritation. Routes of entry includes inhalation, skin contact and eye contact. Moreover, titanium powder poses a significant fire hazard and, when heated in air, they are prone to explosion.
Therefore, it is important to increase the surface hardness of the titanium alloys in order to enhance their wear resistance. As it is almost impossible to improve the tribological behavior of the whole material, it is better to modify the surface properties of the substrate using different techniques such as boriding, carburizing, nitriding, PVD and CVD etc. [5-11]. The purpose of all these treatments is to fabricate a hard and wear resistant layer on Ti based alloys. TIG surface treatment is one of the surfacing methods which is aimed at melting and alloying localized region of the metal in order to modify the surface properties of the titanium alloys [12]. In this method a TIG welding machine is used as an energy source to melt or fuse the alloying elements on the surface of the material to produce a hard coating [13]. The technique of TIG surface engineering had been adopted in industry to produce auxiliary surface coatings on a wide range of ferrous and non-ferrous metals [14,15]. Theoretically, this method also can be appropriately applied to the titanium alloys to form a hard Ti matrix interface layer with improved surface hardness [16,17]. There are many kinds of alloying elements or intermetallic particles such as Ni, Mo, WC, TiC, SiC, NiCrBSi, Si_3N_4, etc. that can be cladded or alloyed on Ti alloys [18-20]. In this project a mixture of Mo and TiC powders are used as alloying element.

2. Materials and Methods

In this project, CP Ti plates were chosen as the base material. Wire-cut machine was used to cut the substrate into 100 mm ×25 mm×10 mm pieces. Before liquid phase surface treatment, all of the specimens were ground with sand paper up to 800 grits in order to remove the oxide layer and then

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ultrasonically cleaned with acetone. The Mo and TiC powders was replaced on the substrate by the means of plasma spraying (APS) with a thickness of about 200 µm. APS parameters are shown in Table 1. The size of Mo and TiC particles were about 45µm and 75µm respectively. The powders of molybdenum and titanium carbide were mixed in different ratios or percentages by weight according to Table2.

After preplacing the alloying elements on the Ti substrate, the specimens were put into a 100ºC oven to release any moisture from the sprayed layers.

An in-situ alloyed layer was fabricated using TIG process on CP-titanium by melting the pre-coated substrates. A tungsten electrode with a diameter of 2.4 mm was used to create an arc between the tip of the electrode and the substrate surface. The voltage (V) on tungsten electrode was maintained at 15 V.

During TIG surface treatment, a melting pool was formed on the surface samples. As titanium alloys can be oxidized readily at high temperature, it was urgent to use a sufficient shielding technique to avoid oxidization. The side jet or coaxial of argon shielding gas did not provide enough oxidization prevention in the TIG surface treatment process. In this project, an argon-shielding box was used for oxidization prevention as shown in Fig. 1.

Specimens were cut transversely, polished and then etched in a solution containing 5 ml HF, 15 ml HNO3and 80 ml H2O for 15 seconds. Moreover, microstructural characterization was done by the means of optical and a Cam Scan (MV2300) scanning electron microscope (SEM).

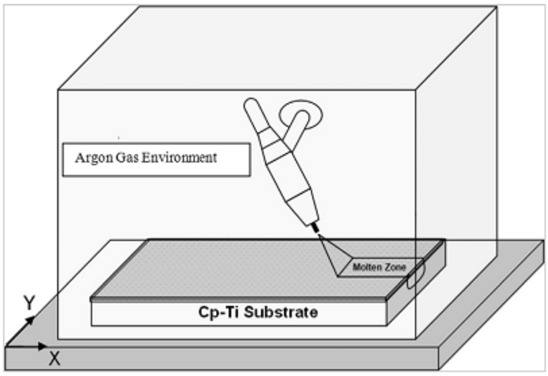

Fig. 1. Schematic view of argon shielding box.

The SEM was equipped with an Oxford Inka200 energy dispersive spectrometer (EDS) for the evaluation of chemical composition. Hardness tests accomplish using a Micro Met microhardness tester under a 3 N load. In order to measure the sliding wear resistance of the coatings, a pin on disc wear test were performed. Pins were provided into size Ø = 5mm using wire-cut technique. The wear test parameters include: normal force (N) of 50 N, sliding speed (S) of 2 m/s, and sliding path (D) of 3600 m for each sample. The disk used for direct sliding contact was made of hardened AISI 52100 steel with hardness of 64 HRC.

Table 1. Atmospheric plasma spraying (APS) parameters.

System	Plasma Technik A30005
Gun	Sulzer metco F4
Flow rate of carrier gas (Ar)	8 lit/min
Flow rate of primary gas (Ar)	60 lit/min
Flow rate of secondary gas (H_2)	14 lit/min
Rate of powder injection	25 g/min
Arc voltage	75 V
Arc current	530 A
Distance of spraying	12 cm

Table 2. The wt. % content of the Mo and TiC particles in the APS pre-placed Coating.

Sample	Mo (wt. %)	TiC (wt. %)	Thickness of sprayed layer(µm)
Mo100	100%	0%	200
Mo80-TiC20	80%	20%	200
Mo60-TiC40	60%	40%	200
Mo40-TiC60	40%	60%	200
Mo20-TiC80	20%	80%	200
TiC100	0%	100%	200

3. Results and Discussion

The microstructures of the sample coated with 100% Mo is depicted in Fig. 2. This micrograph was provided using an SEM, which was managed in backscatter mode. The alloyed layer includes fine dendritic grains, which are homogeneously dispersed in the whole alloying zone.

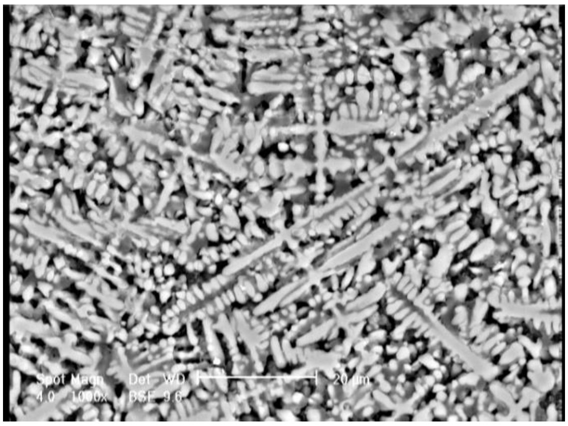

Fig. 2. The microstructure of the treated layer sprayed with 100% Mo.

As the backscatter mode is used in this SEM image, the dark areas have a smaller atomic mass compared to the bright areas. It can show that the bright areas include high content of molybdenum which is due to its higher atomic mass compared to the Ti. It should be noted that, according to Fig. 3. the results of EDS analysis confirm that the bright areas contain more content of Mo than Ti. On the other hand, Fig. 4. proves that in the dark regions, the ratio of Mo to Ti is decreased.

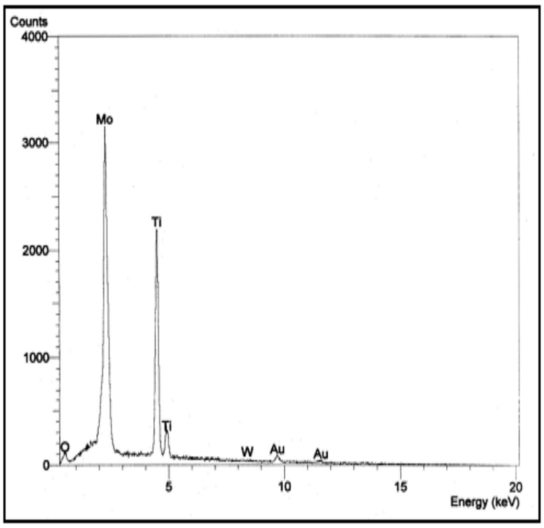

Fig. 3. EDS chemical analysis of bright areas in the treated layer sprayed with 100% Mo.

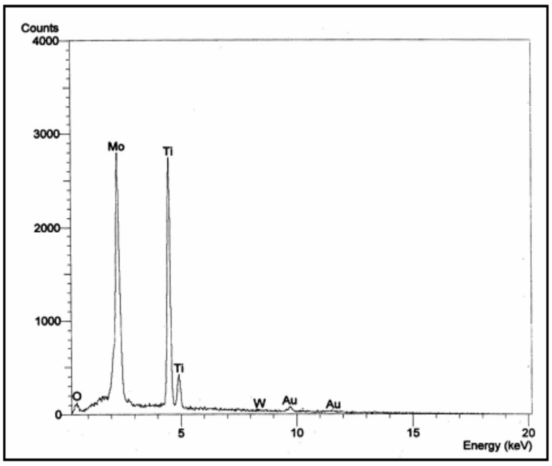

Fig. 4. EDS chemical analysis of dark areas in the treated layer sprayed with 100% Mo.

Fig. 5. also reveals that the increasing of the weight percentage of TiC in a pre-sprayed powder leads to appearance of some un-melted TiC particles on the surface treated region. This fact is related to its high melting point.

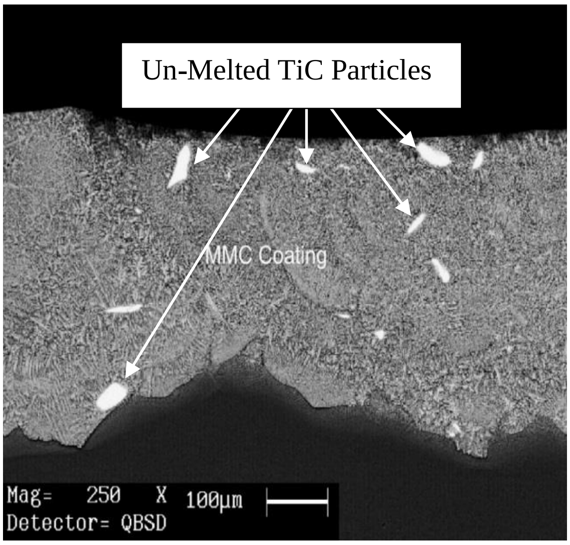

Fig. 5. Microstructure of treated layer sprayed with 80%Mo and 20%TiC.

Fig. 6a, b and c depicts the SEM micrographs of the coatings fabricated with different ratios of Mo and TiC. It is obvious that raising the weight percentage of titanium carbide in the preplaced powder resulted in an increase in the amount of un-fused TiC powders inside the surface melted layers. The presence of TiC particles in the melted layers can increase the surface hardness and wear resistance of the coatings which is due to the high hardness TiC intemetallics. Zhang, et al. also confirmed that the in-situ synthesis of TiC particle as reinforcement on Ti-6Al-4V alloy improved both surface hardness and wear resistance of the coatings [18].

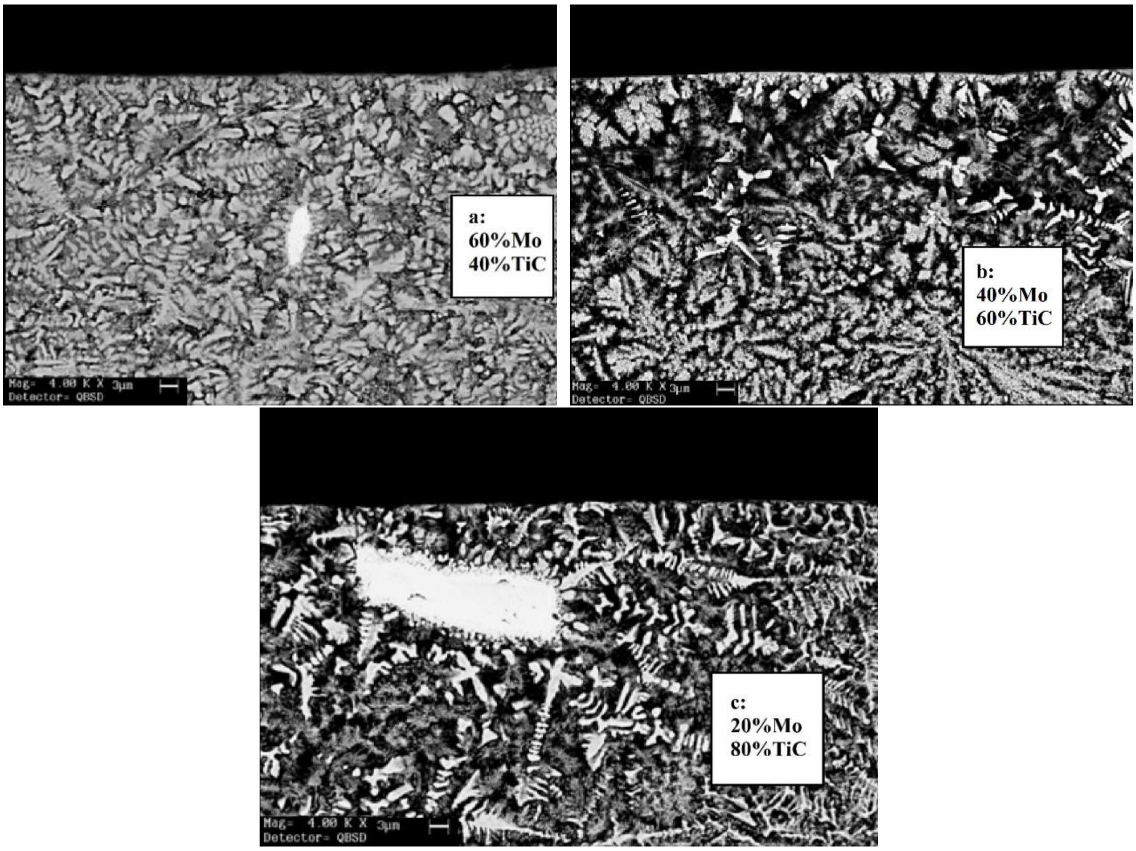

Fig. 6. The microstructures of treated layers with different ratios of Mo and TiC. (a) 60%Mo/40%TiC, (b) 40%Mo/60%TiC, (c) 20%Mo/80%TiC.

The results of microhardness tests are illustrated in Fig. 7. It shows an upward trend in the average microhardness of the coatings by increasing the weight percentage of TiC in the pre-sprayed powder. This increasing in the hardness of the TIG treated layers is attributed to the increase in the amount of TiC hard intermetallic particles in the microstructure which is in accordance with the results of Yun et al. experiments [19]. TIG surface alloying with pure Mo improved the hardness of the surface layers up to about 360 Vickers compared to CP Ti with the hardness of 180 Vickers. In the case of applying 100% TiC in the preplaced powder, the microhardness improved up to more than 600 Vickers. So it can be concluded that it is possible to improve the surface hardness to about 300% more than the as received commercially pure titanium.

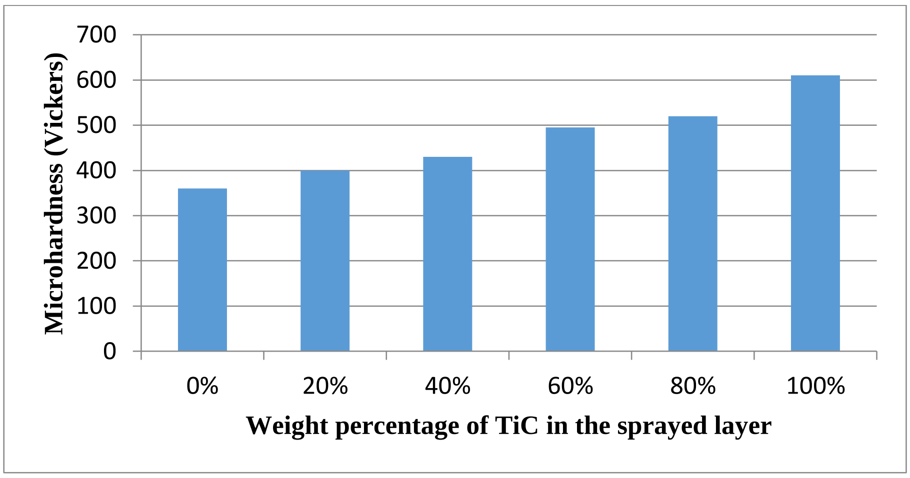

Fig. 7. Microhardness of treated layers with different ratios of Mo and TiC.

Fig. 8a shows that the microhardness improvement resulted in decreasing the mass loss of treated layers during wear test which means that the wear resistance is increased. Actually, TiC particles played the role of reinforcements and improved the performance of the coating during wear test. Sun, et al [20]. also reported that during laser cladding of Ti-6Al-4V alloy with TiC and TiC+ NiCrBSi powders, increasing the microhardness leads to improve the tribological behavior and wear resistance. Moreover, it should be noted that comparing the wear test results of as-received commercially pure titanium and treated layers demonstrate that the surface modification technique improved the wear resistance of the substrate by 60-150 times (Fig. 8b).

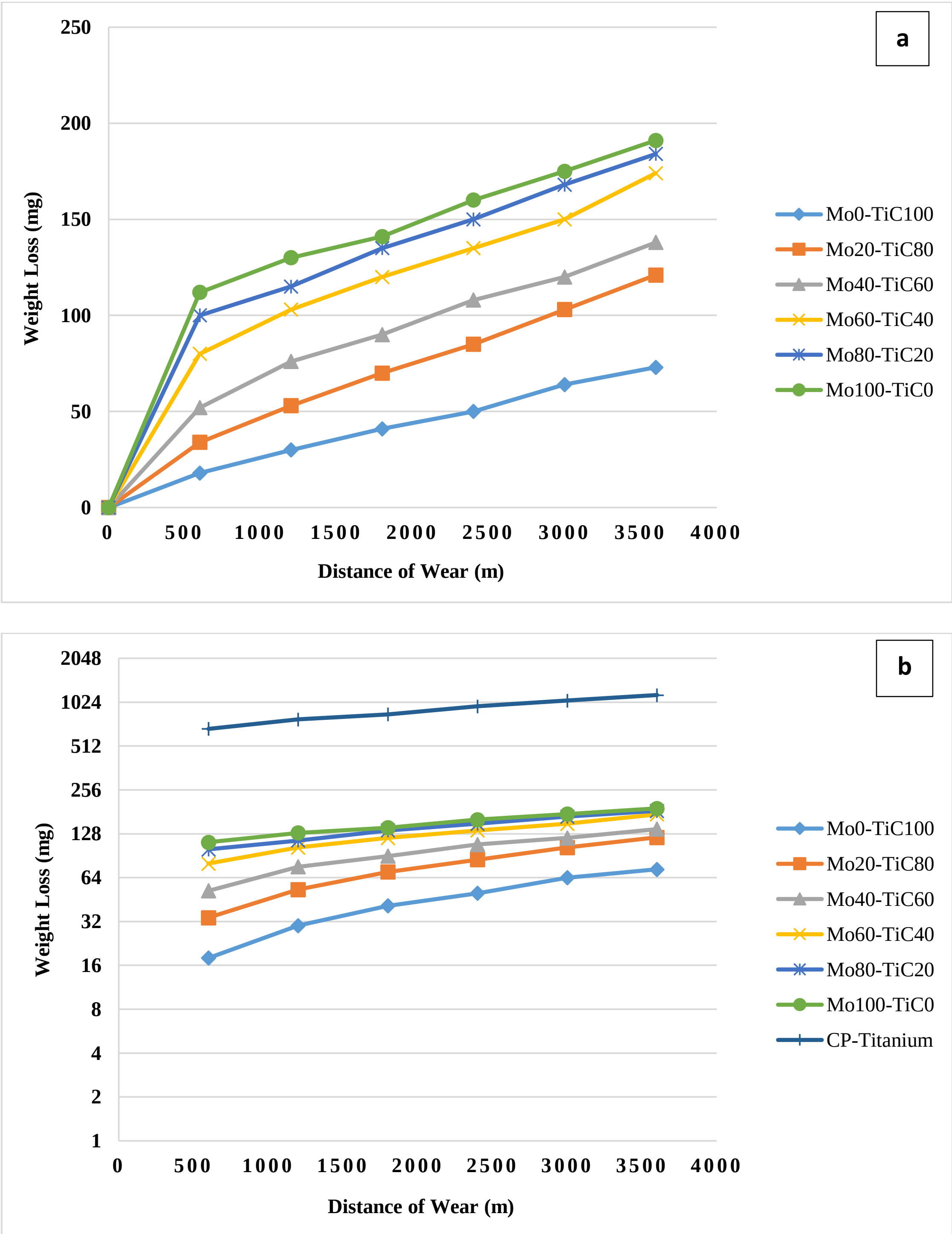

Fig. 8. Mass loss versus time of wear (a) coatings with different ratios of Mo and TiC, (b) different coatings in comparison with CP-Ti in logarithmic scale.

4. Conclusions

1. TIG surface modification of commercially pure Ti was successfully carried out by TIG surface melting of Mo–TiC preplaced substrate.
2. As a result of this process the microhardness and wear resistance of the coatings was improved in order to prevent the entry of its dark-colored dust which would impact the environment.
3. The SEM micrographs illustrated that the microstructures of the modified layers contains fine dendritic grains, which are homogeneously dispersed in the whole alloying zone along with some un-fused TiC particles.
4. There was a perfect bonding between the coatings and the substrate which is appropriate for actual wear applications.
5. It was found that the hardness of the treated layers was more than three times higher than that of the CP-Ti substrate.
6. The wear resistance of this coating was found to be between 60 to150 times better than those of the base material**.**

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