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The Ceramic Composite Coating ($TiC+TiB_2$) by ESD on Ti6AL4V Alloy and Its Characterization

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ABSTRACT

Titanium based alloys or materials used for mechanical and constructional purposes can exhibit high corrosion and abrasion resistance with coatings made on their surfaces. In this study, the surface of Ti6Al4V plate substrate was coated with $TiC+TiB_2$ composite electrodes at different volts and frequencies by Electro-Spark Deposition (ESD) method. The ESD method is a micro arc welding method that allows deposits of alloys and ceramics compounds that have electrical conductivity on the surface of metallic materials, with the plasma that brings about a better melting of base metal and electrode for producing good adhesion between the coating and base metal. In this study, the Ti6Al4V samples were coated with $TiC+TiB_2$ electrodes, and the precoating, post-coating hardnesses, wear rates and coating layer thicknesses of the samples were examined. TiC + TiB_2 composite coating on the surface of Ti6Al4V alloys by ESD method was achieved and the hardness increase was observed with the help of numerous hard ceramic phases.

Keywords: ESD Coating; $TiC+TiB_2$; Ti6Al4V

1. Introduction

When the working principles of the used machines, devices and equipments are examined, most of the machines only wear from the working surfaces. These worn surfaces have a low or high coefficient of friction compared to the other equipments of the machine. Engineers need coatings to be more resistant to heat, abrasion and corrosion than the working area. To meet these conditions, the chemical and physical properties of the desired conditions on the surface of the material are provided through various technological processes[1-3].

Electro-spark deposition process (ESD) produces a spark which consists of electrical charge discharges with arc plasma, generating variable frequency and voltage to deposit a desired electrode material on a metallic or conductive substrate surface in order to correct the wear, wear and dimensional changes caused by defect occurring on the material surface[4-7]. Short pulse durations transfer small droplets during each pulse results which produce high cooling rates i.e. 105 ℃/s[8,9]. The cooling rate is high enough to produce amorphous alloys and glasses[10].

Kovacik *et al*. was successfully completed coating of Ti6Al4V substrate with TiB_2 by ESD method and EDX microanalysis showed that coating hardness increased due to the formation of precipitated alumina, TiB_2, and other more complex phases during the ESD process[2]. The TiC-TiB_2 composite coating electrode was used for coating with electro spark deposition method on the surface of 40Cr steel, and the results showed that the main phases of the composite coating were TiB_2, TiC and Fe_3C. The micro hardness distribution throughout the depth of the composite coating was homogeneous and the microhardness value of the composite coating was measured to increase to about 4 times the hardness of the base material. The wear mechanism of the coatings may differ from the wear mechanism of the base material.

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For example, while the wear mechanism of 40Cr steel is mainly related to micro shear, the wear mechanism of composite coating emerges as a mixture of micro shear, scratch and fatigue wear[4,6].

In this study, $TiC+TiB_2$ coating process was performed on Ti6Al4V plates using ESD coating method

2. Materials and methodology

2.1 Materials used in experiments

Samples with dimensions of 20 × 20 × 1 mm were used in the experimental studies. The chemical composition of the Ti6Al4V alloy and $TiC+TiB_2$ composite coating electrode produced by powder metallurgy used in the experimental studies is given in **Table 1**.

2.2 ESD coating

The test setup prepared for the coating process is given in **Figure 1.** Coating was performed at 230 rpm, 42, 92 and 115 V and 550 Hz and 1570 Hz coating frequencies. Argon gas was purged onto the coated metal surface in order to make the coating easier to perform, to reduce splash and improve the adhesion, as well as to minimize oxidation. The ESD coating time was limited to 2 minutes.

Table 1. Chemical composition of Ti6Al4V alloy and $TiC+TiB_2$ coating electrode used in experimental studies

	Chemical composition (wt. %)			
	Al	V	Fe	O_2
Ti6Al4V	6.4	4.15	0,18	<0,2
	N_2	C	Ti	
	<0,05	0,04	Bal.	
$TiC+TiB_2$ Composite	TiC	TiB2	Co	-
	60	30	10	

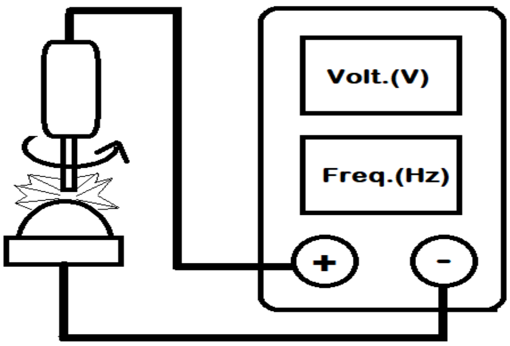


Figure 1. ESD Coating device setup.

Table 2. The parameters for coating

Substrate	**Coating Conditions**
Ti6Al4V	43 V, 550Hz
	92 V, 550Hz
	115 V, 550Hz
	43 V, 1570Hz
	92 V, 1570Hz
	115 V, 1570Hz

During the coating process, while the backing materials rotate at a certain speed, the vibrating applicator is contacted on the part and sparking is ensured and metal transfer is performed for the coating. The parameters used for coating of Ti6Al4V plates are given in **Table 2**.

2.3 Metallographic studies

The specimens prepared for metallographic examinations were sliced to observe the cross-section of the coating layer and passed through various abrasive papers and finally polished with 1 μm alumina paste. The polished surfaces were lightly etched in 1% HF solution. Layer thicknesses were examined by Olympus BX-60 optical microscope and LEO 1430 VP SEM microscope.

The layer thickness was determined by averaging at least five measurements made from the cross section of the metallographic sample. XRD analysis of samples were carried out with Shimadzu XRD – 6000 X-ray Diffractometer using CuKα (λ = 1.5406 Angstrom) radiation between 20–90 degrees. Hardness measurements of the coatings on the surface of the samples was done with the micro-hardness tester of SHIMADZU HMV-2 model under the load of 50 gr with the Vickers tip; average values are calculated by taking 5 measurements at different locations on the samples-layer interface.

3. Results and discussion

3.1 Microstructural analysis

Figure 2 shows images of $TiC+TiB_2$ composite coatings taken at macro magnification, i.e. around 3x. The horizontal axes from the top left are 48 V, 92 V and 115 V, while the columns show the frequency of coatings at 550 Hz and 1570 Hz from left to right. The coating areas are in the same size and the coating morphology shows that the best coatings parameters are visually 550 Hz/115V and 1570 Hz/115V. It is desirable that the surface roughness of the coatings has a minimal effect and exhibit a homogeneous appearance. It is obvious that as the coating voltage increases the number of dark features that are the indication of oxidation and evaporation of such oxides during the arc process[7] also increases possibly as a result of low rotation speed of applicator which contains the electrode. However, the heat input in the plasma also increases and the size of the droplets tend to become enlarged as with the increase in ESD power or coating voltage.

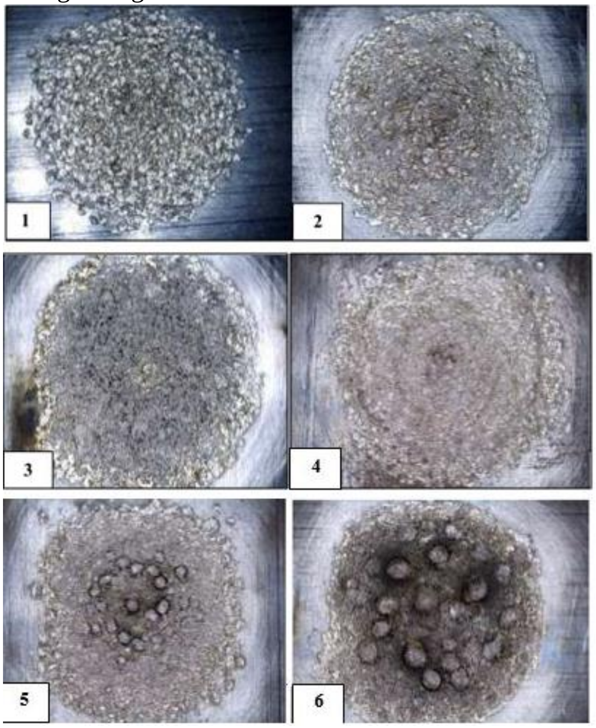


Figure 2. Optical pictures of $TiC+TiB_2$ coated surfaces by ESD method.(1: 43 V, 550 Hz, 2: 43 V, 1570 Hz, 3: 92 V, 550 Hz and 4: 92 V, 1570 Hz, 5: 115 V, 550 Hz and 6: 115 V, 1570 Hz).

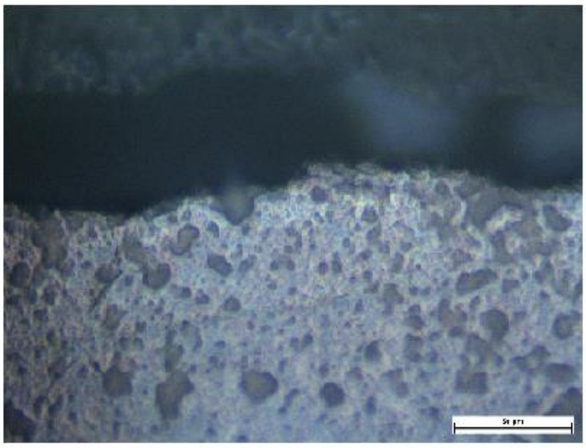


Figure 3. The ESD coating on Ti6Al4V alloy using $TiC + TiB_2$ composite electrode (Scale bar is 50 µm).

Although there are multiple layering on top of the coating, i.e. the formation of multiple drop accumulation, it has a very homogeneous morphology. No cracks occurred parallel to or perpendicular to the matrix. It is known that some formations reduce cracking and increase homogeneity[5,6] in which case the alloying in the coating is thought to better tolerate the formation of TiC and TiB_2. Layered structures are seen as a result of repeated droplet transfer on the coatings made on steels, in this case, no layered structures have been formed. Ti's weakness in heat transfer and easy alloying are effective in this situation.

3.2 Layer thickness and microhardness

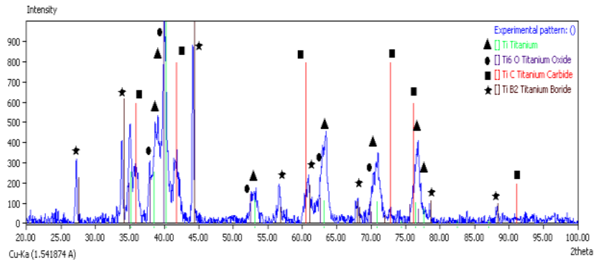
Thickness and hardness of the coatings produced by ESD are given in **Table 3**. The thicknesses of the coatings on Ti6Al4V alloy range from 11 µm to 44 µm. When the obtained hardnesses are taken into consideration, the hardness of all samples increased and the increase in hardness is more obvious especially in high frequency coatings. The highest average hardness was obtained in 550 Hz and 1 different voltage combinations, while the lowest hardness was obtained in 1570 Hz and three different voltage combinations. Although the hardness value of Ti6Al4V is approximately 595 HV, it is seen that the hardness value reached a value much higher than the matrix hardness. The high hardness effect of TiC + TiB_2 and the amount of matrix hardness, as well as the rapid cooling of the ESD process, caused overall the layer hardness to increase.

Table 3. Layer thicknesses and hardness values

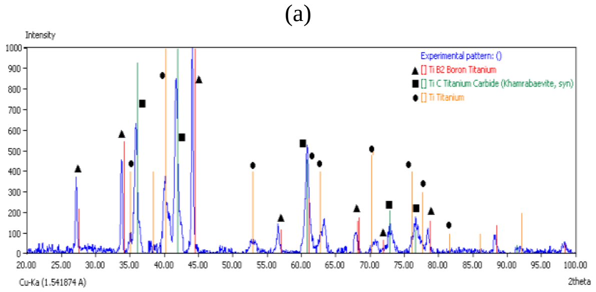
	Coating Conditions	**Coating Thickness (µm)**	**Matrix hardness (HV0.05)**	**Coating hardness (HV0.05)**
Ti6Al4V	43 V, 550 Hz	44±11.2	595±8	1016±75
	92 V, 550 Hz	17±4.3		901±82
	115 V, 550 Hz	20±5.5		852±19
	43 V, 1570 Hz	11±3.9		980±23
	92 V, 1570 Hz	12±4.5		1318±64
	115 V, 1570 Hz	12±6.1		1132±98

3.3 XRD Analysis

Figure 4 shows the XRD analysis result of the coating at 1570 Hz and 115 V. In the Ti6Al4V alloy structure, there is no intermetallic detectable by XRD. But, besides the alloying of B and C from the coating, it is seen that during the formation of the droplets, O_2 in the plasma gas and protective gas causes the formation of oxides of chemically active elements as well as Ti. The coexistence of both phases after the coating shows that the alloying is homogeneous along the surface, although the layer is thin. High voltage or high heat input, in general, reduces the surface area of droplets and chemical activity is restricted to smaller area of reaction and the number of reaction products is reduced in such cases even though the heat input is high. It is also possible to assume that the higher arc plasma temperatures would also lead to the evaporation of some reaction products during the coating process.



(a)



(b)

Figure 4. XRD analysis of TiC + TiB_2 coated Ti6Al4V by ESD method (a) 43 V, 550 Hz and (b) 115V, 1570 Hz.

Through the application of TiC+TiB_2 coatings on the Ti6Al4V surfaces, it is proposed that, given the surface roughness is within the limits, high temperature endurance will be improved as the ESD process in fact alloys the surface with TiC+TiB_2 electrode and create a coating with different composition. With ESD coating, ultra hard surfaces were obtained by applying TiC coating on unalloyed carbon steel samples to TiB_2 or unalloyed low carbon steels[11,12]. 1542 HV hard coating was obtained by using ceramic layer such as Cr_7C_3 or Fe based amorphous alloy (Fe, Cr, Mo, Cd, C, B) electrodes on AISI 304 stainless steel[13,14]. Coatings on this particular Ti alloy is presumed to be as successful as stainless steel surfaces that have been successfully subjected to high impact abrasion and torsion tests, and stainless steel samples have been found to show high resistance against abrasion and torsion[14]. The use of such composite electrodes is advantageous as it will provide more compromised and well balanced properties in regard to industrial applications.

4. Conclusions

The following conclusions were obtained by coating Ti6Al4V with TiC+TiB_2 composite coating electrode by ESD coating method:

TiC + TiB_2 composite was successfully coated on the surface of Ti6Al4V alloys by ESD method.

TiC+TiB_2 coated surface gives the best morphology at high frequency 1570 Hz and medium voltage of 92V.

Ti6Al4V alloyed with ESD TiC + TiB_2 coating as a result of coating different phases formed. TiC and TiB_2 peaks were observed separately in the other residues while oxide was formed at low voltages.

As a result of the coating, coating layer thicknesses between 11 µm and 44 µm were obtained on the surface. Surface hardness of Ti6Al4V alloys increased with TiC + TiB_2 composite electrodes.

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