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Mechanical performance of in-situ $TiC-TiB_2$ composite coating deposited on Ti-6Al-4V alloy by powder suspension electro-discharge coating process

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ABSTRACT

Hard and wear resistance $TiC-TiB_2$ coating was deposited on Ti-6Al-4V alloy by electro-discharge coating process using Ti and B_4C powder suspended kerosene dielectric. Formation of TiC and TiB_2 in combination with some intermediate phase via in-situ reaction of Ti and B_4C due to spark energy has been confirmed through the XRD analysis of the coating. The microstructure analysis executed through SEM and corresponding EDS revealed that the peak current and duty factor has significant effect on the morphology of the coating. The microhardness measured at the top surface as well as at the cross-section of the coating show upto three times improvement in the hardness value compared to the Ti-6Al-4V substrate. The sliding wear test of the coating carried out against WC-Co ball revealed that the wear resistance of the coating improved upto seven times than the uncoated Ti-6Al-4V substrate.

1. Introduction

Ti-6Al-4V alloy have received considerable attention in aerospace, biomedical and power generation industries due to its high strength to weight ratio, corrosion resistance, and high melting temperature [1]. However, the prolonged application of this alloy is limited under severe wear and frictional condition due to its relatively low hardness and poor resistance to sliding wear [2]. Hence, it is indispensable to improve the tribomechanical properties of Ti-6Al-4V alloys by employing a hard and wear resistance coating on its surface.

Various surface modification techniques i.e. laser coating, gas tungsten arc weld (GTAW) cladding, thermal spraying and physical vapour deposition (PVD) were actively employed to improve the surface properties i.e. hardness, wear resistance, and corrosion resistance of Ti-6Al-4V alloy [3–6]. Nevertheless, many of these methods require expensive and sophisticated apparatus with high running and maintenance cost. Electro discharge coating or alloying (EDC/EDA) technique is an alternative approach to produce a hard and wear resistance layer on metallic substrate by utilizing the electrical discharge creates between the tool electrode and the workpiece in a general purpose electro discharge machine (EDM) setup [7]. Surface modification by EDC/EDA usually performed either by using powder metallurgy (PM) tool electrode or by suspension of powder in the dielectric [8]. The preparation of a powder compact tool electrode makes the PM based EDC process more complicated and time consuming. On contrary, EDC by powder suspension method is a recent improvement, where the powder of the desired coating material mixed in a dielectric, and the spark generated between the tool electrode and the work-piece. The powder particles in the dielectric react with the decomposed carbon from the dielectric and produces metallic-carbide that deposited as a hard layer on the workpiece surface [9].

Over the years, various researchers have investigated the effectiveness of the EDC process on different types of steel and aluminium [9–11]. In most of the cases, TiC and WC coating was deposited by using green compact tool electrodes, which delicately improved the hardness and wear resistance of the substrate surface [10,12]. However, specific advantages of the powder suspension method, made the process more prevalent than the PM tool electrode method in recent years. Kumar and Batra [9] revealed that under suitable condition for using tungsten powder mixed dielectric, substantial amount of tungsten particles transferred to the workpiece surface and deposited as tungsten carbide after the reaction with the decomposed carbon from the dielectric. Surface modification of tungsten carbide was performed by EDC process utilizing titanium powder suspended dielectric that produced TiC coating on the substrate surface with a hardness value up to 1750 HV [13]. Arun et al. [14] deposited Ni-WC layer on tool steel by EDC process using nickel and tungsten powder mixed dielectric, which exhibited three times higher hardness as compared to the base material. From the literature, it is evident that the EDC process predominantly

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employed for the surface modification of different types of steel to improve their hardness, wear resistance and corrosion resistance properties. However, surface modification of Ti-6Al-4V by using powder suspension EDC process hardly encountered before. Using conventional solid electrode and powder compacted copper electrode, surface modification of Ti-6Al-4V was carried out, which ascertain the effectiveness of the PM electrode in terms of its affinity towards the alloy formation with the substrate than those obtained by using solid electrode [15].

TiC-TiB_2 composite is a promising coating material that combines the properties of both TiC and TiB_2, and exhibits significant improvement in the hardness, wear resistance and corrosion resistance of the substrate materials [16]. Although, the deposition of TiC-TiB_2 coating on a metallic substrate by conventional coating techniques like PVD [17], plasma spraying [18], laser cladding [19,20], or electro spark deposition [21] is common; however, investigation on the deposition of TiC-TiB_2 coating by EDC process rarely reported. Very recently, TiC-TiB_2 ceramic composite coating was deposited on aluminium substrate by EDC method with the help of powder metallurgy tool electrode prepared with Ti and B_4C [22]. From the literature, it is also revealed that TiC-TiB_2 composite can be produced by in-situ reaction of Ti and B_4C under appropriate condition [23], which has specific advantages than the ex-situ formed TiC-TiB_2 composite. Li et al. [24] fabricated in-situ synthesized TiC-TiB_2 reinforced Ti-based composite coating on Ti-6Al-4V by laser cladding process that exhibited elevated hardness and wear resistance along with superior metallurgical bond with the substrate.

The powder suspension EDC technique is a reformation of EDC process and was employed for surface alteration of different substrate materials by depositing various hard and wear resistant coating materials. However, as per author's knowledge, very limited work has been reported so far, on the surface modification of Ti-6Al-4V by powder suspension EDC method. In this work, an attempt has been made to deposit TiC-TiB_2 coating on Ti-6Al-4V alloy by powder suspension EDC process using Ti and B_4C powder mixture in kerosene dielectric. Effects of EDM process parameters i.e. peak current (Ip) and duty factor (τ) on the deposition of the coating material have been evaluated. Micro-hardness of the produced coating has also been measured and the effects of process parameters on these performance characteristics have been evaluated. A detail microstructural assessment of the coating cross-section has been carried out through the scanning electron microscopy (SEM) and corresponding energy dispersive spectroscopy (EDS). In addition, the sliding wear behavior of the produced TiC-TiB_2 coating has been analyzed and correlated with the microstructure and hardness of the coating.

2. Experimental planning and procedure

For the present work, 3 mm thick Ti-6Al-4V alloy plate was selected as substrate material, chemical composition of which is illustrated in Table 1. Prior to the initiation of the EDC process, the surface of the substrate was polished with SiC based emery paper (600 mesh size) to remove the oxide layer and any undesired surface defects present. The electro discharge coating was performed using a die sinking electro-discharge machine (EDM) (ELECTRONICA LEADER-1, ZNC version ELEKTRAPULS PS 50) modified with a separate tank to accommodate the powder mixed dielectric and stirrer arrangement. Ti (Avg. particle size: 8–10 μm) and B_4C (105 μm, make: Loba Cheme) powder mixed at 3:1 wt. ratio (stoichiometric ratio as per Eq. (1)) and blended in a planetary ball mill for 3 h, to obtain a refine and uniform powder mixture. Then, 50 g of the powder mixture was dispersed in 5 l of kerosene to be used as a dielectric mixture. A 12 mm diameter commercially pure cylindrical copper rod with a flat end was used as tool electrode. Prior to each experiment, the surface of the tool was polished to make it uniform, and eradicate any impression induced due to the previous experiment.

Table 1
Chemical composition of Ti-6Al-4V.

Element	Ti	Al	V	Fe	C
Wt%	90	5.5–6.76	3.5–4.5	<0.25	<0.08

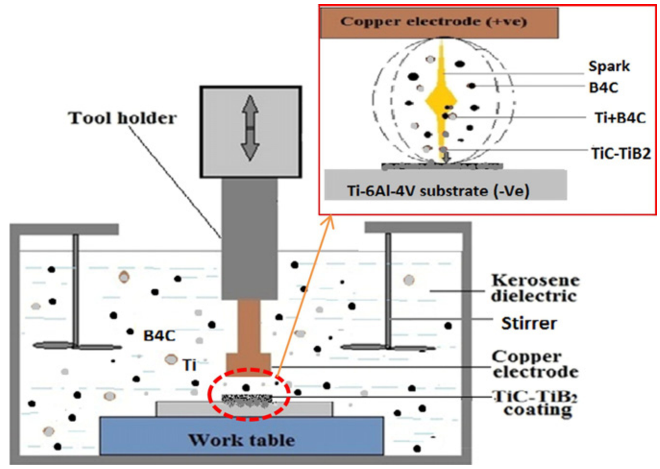

Fig. 1. Schematic diagram of EDC process by powder suspension method showing the formation and deposition of TiC-TiB_2 on Ti-6Al-4V substrate.

Fig. 1 illustrates the schematic diagram of the experimental setup for the EDC process by powder suspension method. Prior to initiate the present set of experiments, some preliminary study was carried out by using Ti and B_4C powder mixture suspended kerosene dielectric on Ti-6Al-4V substrate and considering EDM parameters i.e. peak current, duty cycle, and pulse duration for a wide range [25]. It was revealed that higher duty factor (above 70%) and relatively lower peak current contributed towards the uniform deposition of the coating material on the Ti-6Al-4V substrate. In consequence of these results, the parameters and their ranges have been selected for the present set of experiments. To attain an acceptable coating thickness and to evaluate the effect of specific EDM parameters in EDC process, experiments was performed by varying the peak current (Ip) and duty factor (τ) as depicted in Table 2. The other parameters i.e. polarity (negative), gap voltage (40 V), pulse on time (200 μs) and the experimental time (5 min) were kept constant for the entire set of experiments. During the EDC process, the deposition rate of the coating material was assessed from the weight difference of the substrate before and after the experiment, and considering the experimental time.

After the deposition of TiC-TiB_2 coating on Ti-6Al-4V substrate, the coated samples were endured for further analysis. The compound phases produced and deposited during the EDC process were identified through X-Ray diffraction (XRD) technique using a multipurpose X-ray diffraction system (Make: Rigaku, Ultima IV) operating with the copper target ($\lambda = 1.5418$ Å). The morphology of the coating microstructure

Table 2
Detail experimental plan.

Exp. no.	Ip [A]	τ [%]
1	3	70
2	3	75
3	3	80
4	4	70
5	4	75
6	4	80
7	5	70
8	5	75
9	5	80
10	6	70
11	6	75
12	6	80