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Effect of cryogenically treated copper-tungsten electrode on tool wear rate during electro-discharge machining of Ti-5Al-2.5Sn alloy

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ABSTRACT

Titanium, due to its excellent properties with high strength to weight ratio, is increasingly being used for various applications. Electric discharge machining (EDM), due to its unique features, is extensively used for machining of titanium and its alloys as it is difficult to machine titanium with conventional machining. EDM, however is most suited for electrically conductive materials and to make up for the poor thermo-electrical properties of Ti-5Al-2.5Sn titanium alloy, deep cryogenic treated (−184 °C) copper-tungsten (Cu-W) tool has been used in this study for machining. This study reports the effect of deep cryogenic treatment (DCT) on tool wear rate during electric discharge machining of Ti-5Al-2.5Sn titanium alloy by varying various process parameters namely cryogenic treatment of electrode material, peak current, pulse-on & off time and flushing pressure. Fractional factorial experimental design was used for designing the experimental study and the results were statistically analyzed to obtain optimal combination of input process parameters for minimizing tool wear. Peak current was observed to be the most significant process parameter in relative comparison to other input parameters. The results show a significant reduction in tool wear rate in case of DCT Cu-W electrode when compared to untreated Cu-W electrode. Surface characteristics of select Cu-W electrode and workpiece samples were analyzed using scanning electron microscope (SEM), energy dispersive spectrograph (EDS) and X-ray diffraction (XRD). Various chemical compounds specifically titanium carbide (TiC) were seen on both the machined and the tool surface due to material transfer during machining.

1. Introduction

Titanium is a low density element which can be strengthened greatly by alloying and deformation processing. When considering alloyed and unalloyed titanium, it is classified into as commercial pure, alpha and near alpha, alpha-beta. Ti-5Al-2.5Sn alloy comes under alpha and near alpha alloy is preferred for high temperature as well as cryogenic applications. The productivity during machining of titanium alloys is adversely affected by rapid tool wear using traditional machining processes due to its poor thermal conductivity and chemical reactivity. Rapid tool wear encountered in machining of titanium alloys is a challenge that needs to be overcome [1].

The Electrical Discharge Machining (EDM) is one of the better options in non-traditional machining processes for machining of titanium and its alloys, because there is no direct contact between the tool and workpiece. EDM is a thermo-electric process in which metal is removed from the surface of workpiece by a repeated electric sparks generates between a work and tool immersed in a dielectric fluid. Due to generation of successive electric sparks high temperature occurs (8000–12,000 °C), resulting in removal of material from workpiece and tool surface by melting and vaporization. Metal is removed from workpiece as well as from the tool in the form of craters. To minimize the wear of tool/electrode machining condition, polarity and electrode material should be selected carefully [2]. In EDM, higher electrical conductivity, good thermal conductivity and low tool wear rate are essential requirement of tool material. Chen et al. observed low electrode wear ratio during EDM of Ti-6Al-4V in distilled water as compared to kerosene dielectric [3]. Yan et al. investigated the machining characteristics of Ti-6Al-4V alloy using two processes EDM and USM jointly and explored that MRR is larger when using distilled water as the dielectric medium than when using kerosene and the relative electrode wear ratio is smaller [4]. Hascalik and Caydas machined Ti-6Al-4V alloy using EDM process with different copper, aluminum and graphite electrodes by varying pulse current and pulse duration. Experimental results showed that electrode

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wear has tendency of increase with increasing current density and pulse duration. Graphite electrode material showed the lowest wear rate due to its higher melting point during all process conditions [2]. Pradhan et al. optimized the machining parameters for micro-EDM of Ti-6Al-4V alloy and reported that peak current has the maximum effect on TWR [5]. Yan et al. used urea solution in water as dielectric during EDM of pure titanium and concluded that electrode wear rate (EWR) increased with increase in peak current. Moreover, EWR decreased with increase in pulse duration [6]. Ferreria used three grades of copper-tungsten (Cu-W) electrodes during EDM of AISI H13 die steel to study surface finish of die helical thread cavity and reported that for Cu20W80 grade, the relative TWR decreases with increasing peak current and decreasing pulse-on duration [7]. Marafona suggested that electrode wear ratio decreases with the increase in percentage of equivalent carbon during erosion period in EDM of BS 4695 D2 die steel with Cu-W electrode [8]. Kao et al. observed that discharge current significantly affected the electrode wear ratio with almost 70% contribution in EDM of Ti-6Al-4V alloy [9]. Tang et al. used tap water in place of hydrocarbon dielectric in EDM of Ti-6Al-4V alloy. Taguchi method with grey relational analysis (GRA) was applied to optimize the multiple characteristics and observed the significant improvements in results [10]. Medellin et al. used the two electrode materials namely brass and bronze in EDM of D2 die steel using the mixture of tap water and deionized water. The experimental results revealed that by using 75% tap water and 25% deionized water mixture as dielectric, the maximum MRR and the minimum EWR can be obtained [11].

The major drawback of the conventional EDM process is low MRR, higher TWR and poor surface finish which restrict its use in manufacturing industries. To improve the machining efficiency of a process, suitable metal particles in powder form are mixed with the dielectric. The powder concentration is the most critical factor that highly affects the machining performance. These metal particles act as a conductor and are responsible for the significant reduction in the breakdown strength of the insulating liquid between the spark gap. Due to contamination, gap size is increased as well as ignition process improved, thus, stability of the machining process is also improved. Due to interlocking of metallic powders, rate of generation of sparks becomes faster, hence, the erosion process becomes faster, causing an increase in MRR and reduction in tool wear. At the same time, plasma channel is modified due to mixed powder particles, thus, uniformly distributes the sparks, which decreases the density of spark. Due to this issue, shallow craters are produced, which improve the surface finish of the machined parts [12,14,15]. Powder or additive mixed EDM is one of the famous hybrid machining process that can be used for enhancing the capabilities of EDM process. In this process, gap between the two electrodes can be reduced resulting in more stable machining, thus, reducing the electrode wear. Researchers used various powders with dielectric and obtained significant improvement in terms of low tool wear and higher MRR with better surface finish [12–18].

Cryogenic treatment or cryogenic cooling method can improve the machining characteristic resulting in reduced tool wear. Results in the literature show tool life improvements from 92% to 817% when using the cryogenically treated HSS tools in the industry [19]. Venugopal et al. reported that cryogenic cooling with liquid nitrogen jets enables substantial reduction in tool wear in turning of Ti-6Al-4V alloy [20]. Abdulkareem et al. investigated the cooling effect of Cu electrode during EDM of Ti-6Al-4V alloy by using liquid Nitrogen (LN2) inside the special designed electrode. This improves the thermal and electrical conductivity of the electrode which results in reduction of TWR by 27% [21]. Gill and Singh investigated the effect of DCT Ti6246 titanium alloy during Electric Discharge Drilling (EDD) and reported reduction of TWR by 34.78% due to increase in thermal and electrical conductivity of the workpiece material [22]. Jafferson and Hariharan compared the experimental results of both cryogenically treated and without cryogenically treated micro electrodes (brass tube, copper tube and tungsten rod). Significant reduction of 58%, 51% and 35% in TWR for tungsten, brass and copper electrode respectively was observed [23]. Kumar et al. reported significant improvement in TWR and wear ratio in EDM of Inconel 718 workpiece when using cryogenically treated copper electrode [24]. Improvement in TWR by application of cryogenic cooling and treatment on workpiece or tool is reported by other researchers [25–29].

Cryogenic treatment aims at improving the EDM efficiency and reducing the tool wear rate. The literature review shows that efficiency of EDM process is significantly impacted by cryogenic treatment and can be enhanced because thermo-electric properties of material are improved. The present study is, therefore, aimed investigating machining efficiency during EDM of Ti-5Al-2.5Sn titanium alloy with deep cryogenically treated (DCT) copper-tungsten (Cu-W) electrode and without cryogenically treated copper-tungsten electrode. The parameters selected for the study were cryogenic treatment of electrode material, peak current, pulse-on-time, pulse-off- time and flushing pressure. Machining efficiency is evaluated in terms of reduction in TWR.

2. Materials and methods

The experiments were conducted on commercial CNC Electric Discharge Machine (Model OSCARMAX S 645 CMAX manufactured

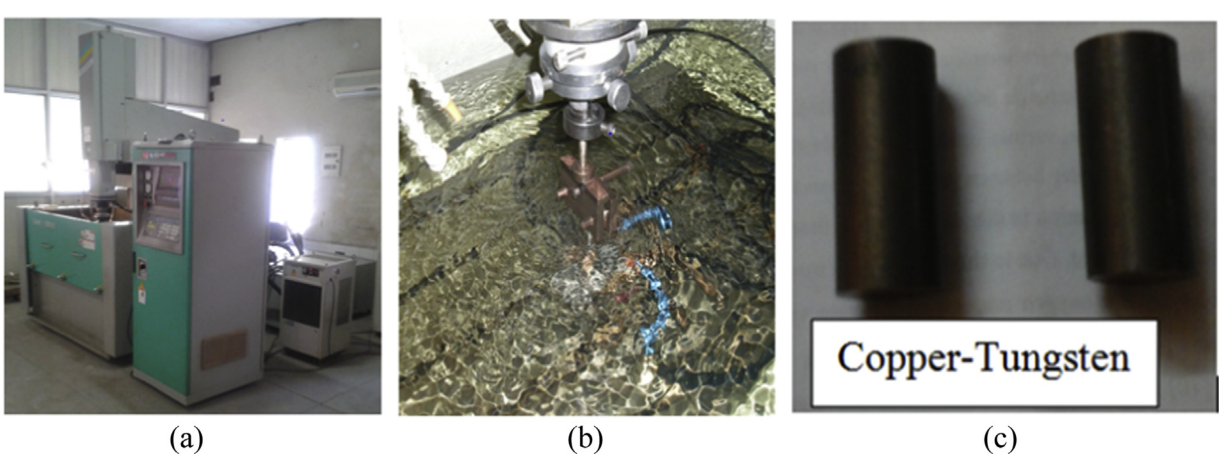

Fig. 1. (a) Pictorial view of CNC EDM machine, (b) Actual machining operation, and (c) Pictorial view of copper-tungsten electrode.