Chinese Journal of Aeronautics, 2013,26(1): 224–229

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

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Wire electrochemical machining with axial electrolyte flushing for titanium alloy

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Received 27 July 2012; revised 5 September 2012; accepted 24 September 2012
Available online 16 January 2013

KEYWORDS

Axial electrolyte flushing;
Electro machining;
Electrochemical machining;
Titanium alloy;
Wire electrochemical machining

Abstract Titanium and its alloys have found very wide application in aerospace due to their excellent characteristics although their processing is still a challenge. Electrochemical machining is an important issue in the fabrication of titanium and titanium alloys. Wire electrochemical machining (WECM) is mainly used for workpiece cutting under the condition of different thickness plates. It has a great advantage over wire electro-discharge machining, which is the absence of heat-affected zone around the cutting area. Moreover, the wire electrode in WECM could be used repetitively because it is not worn out. Thus, much attention has been paid to WECM. The effective way of removing electrolysis products is of importance to WECM. In this paper, the axial electrolyte flushing is presented to WECM for removing electrolysis products and renewing electrolyte. The Taguchi experiment is conducted to optimize the machining parameters, such as wire feedrate, machining voltage, electrolyte concentration, etc. Experimental results show that WECM with axial electrolyte flushing is a promising issue in the fabrication of titanium alloy (TC1). The feasibility of multi-wire electrochemical machining is also demonstrated to improve the machining productivity of WECM.

1. Introduction

Titanium and its alloys are used extensively in aerospace, such as jet engine and airframe components, because of their excellent combination of high specific strength (strength-to-weight ratio) and their exceptional resistance to corrosion at elevated temperature.[1–3] The machinability of titanium and its alloys is generally considered to be poor owing to several inherent properties of the materials. Poor thermal conductivity, chemically reactivity and low elastic modulus are the common problems.

Various techniques in different principles have been developed to produce titanium and titanium alloys features [4–8], including mechanical machining, laser machining, electrical discharge machining (EDM), electrochemical machining (ECM), etc. Titanium is very chemically reactive, and therefore has a tendency to weld into the cutting tool during machining, thus leading to chipping and premature tool failure.[5] Laser and EDM machining usually produce recast layers and heat affected zones which negatively affect mechanical properties of parts.[6–8]

ECM offers another means to produce titanium structures, which is a process to electrochemically dissolve conductive materials at atomic sizes regardless of their hardness and toughness at the anode in an electrolytic cell.[9,10] Over competing technologies, ECM offers some unique advantages, such as

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Peer review under responsibility of Editorial Committee of CJA.

Production and hosting by Elsevier

1000-9361
http://dx.doi.org/10.1016/j.cja.2012.12.026

no tool wear, heat affected zones, residual stresses, cracks, burrs, etc, and therefore it has become an important issue in the fabrication of titanium and titanium alloys.[11–15]

Wire electrochemical machining (WECM) is a cutting process, in which the workpiece acts as anode and the wire as the cathode. A wire-tool constitutes frequently a cheap alternative to a full-form tool, allowing the cutting of intricate shapes without the need for large power supplies, electrode design, and electrolyte flow field design.[16] WECM is mainly used for cutting workpiece with different thickness plates. In principle, WECM is similar to wire electro-discharge machining (WEDM). However, it differs fundamentally from WEDM in the mechanism of material removal. The metal removal is achieved by electrochemical dissolution in WECM, and it is done by spark erosion in WEDM. WECM has a great advantage over WEDM, which is the absence of heat-affected zone around the cutting area. Moreover, the wire electrode in WECM might be used repetitively because it is not worn out.

Bejar and Eterovich reported that the maximum feed rate achieved in WECM of mild steel using a circular wire-tool and an electrolyte of sodium nitrate is greater than what was achieved using a sodium chloride electrolyte.[17] Maeda et al. studied the effect of processing parameters, such as electrolyte flow rate, nozzle diameter, and current density on the maximum feed rate of cutting during WECM.[18] El-Taweel and Gouda investigated the effect of working parameters, namely, applied voltage, wire feed rate, wire diameter, workpiece rotational speed, and overlap distance, on metal removal rate, surface roughness, and roundness error during wire electrochemical turning.[19] Zhu et al. developed a micro-wire ECM to prepare metal microstructure, who adopted tungsten wire electrode with a diameter of 5 μm for producing microstructures with a slit width < 20 μm.[20]

In WECM, the main problem lies in the supply system for the electrolyte. In other words, the effective way of removing electrolysis products is of importance to WECM. It determines the machining accuracy and process stability of WECM. Thus, the removal of electrolysis products has attracted much attention in WECM. El-Taweel et al. employed jet electrolyte flow to renew electrolyte.[19] Wang et al. reported that low frequency and small amplitude tool vibration were helpful to remove electrolysis products and renew electrolyte in micro WECM.[21] Shin et al. used acidic solution because the electrolysis product was metal ion in acidic solution, which was easily removed in WECM.[22]

In this paper, the axial electrolyte flushing is firstly presented to WECM for removing electrolysis products and renewing electrolyte. Compared with jet electrolyte flow, the axial electrolyte flushing might offer uniform flow in working gap, which is helpful to enhance the process stability. The Taguchi experiment is conducted to optimize the machining parameters, such as wire feedrate, machining voltage, electrolyte concentration, etc. Furthermore, multi-wire electrochemical machining with axial electrolyte flushing is presented to improve the machining productivity of WECM.

2. Principle of wire electrochemical machining with axial electrolyte flushing

Fig. 1 illustrates the principle of wire electrochemical machining with electrolyte flushing. Wire electrochemical machining adopts several hundreds of microns wire as tool cathode. It is based on the principle of electrochemical anodic dissolution to remove the workpiece material. The workpiece is connected to the anode of power supply and the wire electrode is connected to the cathode. When voltage is applied to workpiece and wire electrode, dissolution takes place in ion form. The wire electrode is feeding along the defined path, and the corrupting position in the workpiece varies with the location of the wire electrode. During the machining process, the electrolysis products, such as the hydroxides and the hydrogen gas, must be removed and the electrolyte in the machining gap renewed promptly. Otherwise, electric short circuits will frequently occur as the machining gap is accumulated by electrolysis products, and the machining process will become very unstable. In this paper, axial electrolyte flushing, namely the electrolyte flows along the axis of the wire electrode, is adopted to remove the electrolysis products and renew the electrolyte in the machining gap, as shown in Fig. 2. With respect to flushing, the most efficient method of electrolyte delivery is to provide a stream of electrolyte coaxial with the wire. The function of electrolyte flushing is to continuously deliver fresh electrolyte under constant flowrate to the work area. As the stream of electrolyte envelopes the wire penetrating the workpiece, the electrolysis products will be carried away from the machining gap. In the case of electrolyte flow entrance angle being more than 0°, the wire might be deformed due to the impact force of the electrolyte flow, and the processing stability becomes worse. The electrolyte flow with 0° entrance angle is used in this paper. For obtaining coaxial electrolyte flushing, a special fixture is developed, as shown in Fig. 2.

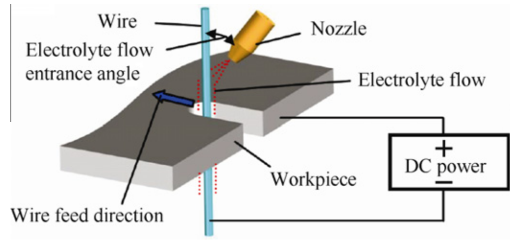

Fig. 1 Schematic diagram of wire electrochemical machining with electrolyte flushing.

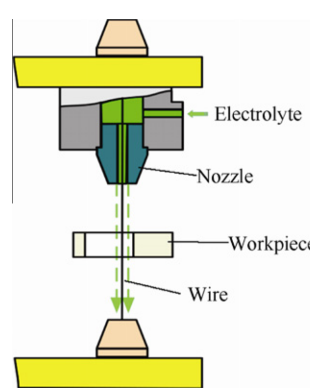

Fig. 2 Sketch of wire electrode fixture for axial electrolyte flushing.