Multi-Feature Optimization of WEDM for Ti-6Al-4V by Applying a Hybrid Approach of Utility Theory Integrated With the Principal Component Analysis

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ABSTRACT

In this study, multi-feature optimization is performed using a hybrid approach of utility theory (UT) combined with the principal component analysis (PCA) during wire electrical discharge machining (WEDM) of Ti-6Al-4V. Taguchi’s L27 orthogonal collection is used to evaluate the effects of the pulse on time, pulse off time, peak current, servo voltage, wire feed rate and cable tension on surface roughness (SR), overcut and metal removal rate (MRR). The utility concept is employed to turn the multi-feature problem into a distinct equivalent feature called as overall efficiency index (OEI). Optimal sets of governing parameters using a hybrid approach are established as the pulse on time 114 machine unit, pulse off time 55 machine unit, servo voltage 20 volts, peak current 190 Amp., wire feed rate 5 m/min and cable tension 2 device unit. Scanning Electron Microscopic (SEM) analysis of cut surfaces shows a lump of debris, microvoids, micro-cracks, and large dark craters at high values of the pulse on time.

KEYWORDS

Overall Efficiency Index, Principal Component Analysis, SEM Analysis, Taguchi Method, Ti-6Al-4V, Utility Theory, WEDM

INTRODUCTION

Titanium is the ninth richest constituent available in the earth’s crust and fourth most structural metal and exotic space age metal. Titanium and its alloys have high strength, low density, low weight ratio, excellent elevated temperature properties, superior corrosion resistance, low thermal coefficient of expansion, non-magnetic, high fracture toughness and fatigue strength, excellent cryogenic properties, high ballistic resistance-to-density ratio and non-toxic, non-allergenic and completely biocompatible. Due to these extraordinary properties, titanium and its alloys are widely used in automotive, aerospace, chemical plant, surgery and medicine, power generation, sports, oil and gas extraction, etc. (Yang & Liu, 1999).

During the cutting off titanium alloys, high temperature up to about 1100°C is produced near to the cutting edge of the tool. As titanium alloys have meager thermal conductivity, nearly 80%
of the heat created, is conducted into the tool which causes accelerated wear of the device. During traditional machining of titanium alloys, a minute area of contact between the chip and tool exist. Also, titanium and its alloys offer resistance to deformation at an elevated temperature which results in the generation of mechanical stresses near the cutting edge of the tool. These stresses are three to four times more than that of nickel-based alloys and steel materials during processing. Low modulus of elasticity leads to chatter while the finish cutting off titanium alloys. Deflection of titanium is twice that of carbon steel during machining, resulting in spring back action at the rear of the cutting edge of the tool. This bouncing action on the forefront leads to premature flank wear, vibration, and a higher temperature at the machining zone. At a high cutting temperature greater than 500°C, titanium, and its alloys chemically react with all the tool materials. While machining of titanium, chips tends to bond to the cutting tool which results in dissolution-diffusion wear which boosts with increasing temperature (Ezugwu & Wang, 1997).

These problems can be reduced by employing unique machining process such as WEDM. It is a thermal energy cutting process in which material is removed by constant and distinct sparks generated in a small space between the wire electrode and workpiece in the company of dielectric. The material removal mechanism in WEDM is primarily due to melting and vaporization. It is used for conductive material machining irrespective of its hardness and toughness. WEDM technology has been widely utilized for the production of mold, dies, medical and dental instrumentation, graphite electrodes, parts of automotive and aerospace industries. In WEDM there are many process parameters involved which are classified into electrical parameters and non-electrical parameters affecting the performance measures namely metal removal rate (MRR), surface finish, surface integrity and dimensional accuracy (Ho, Newman, Rahimifard, & Allen, 2004).

Su and Tong (1997) found that PCA method yields better optimization results as compared to Taguchi method. Kansal et. al. (2006) performed experiments on H-11 die steel during powder mixed electrical discharge machining (PMEDM) process. Taguchi based utility concept was used to determine optimal performances. Gaitonde and Karnik (2007) optimized burr size during drilling of AISI 1018 steel by applying service technique with diverse sets of weights. Gaitonde et. al. (2009) used utility approach combined with Taguchi method for the optimization of MRR and SR while conducting turning experiments on free machining steel. Gauri and Chakraborty (2009) reported an application of weighted principal component (WPC) method and found considerable improvement in quality characteristics. Datta and Mahapatra (2010) conducted turning operations on mild steel. They utilized PCA based utility method for the optimization of various values of surface features. Kumar and Khamba (2010) carried out experiments on pure titanium using ultrasonic machining. For the optimization of MRR, SR and tool wear rate (TWR) utility technique in association with Taguchi method was applied. Badkar et. al. (2011) presented utility concept tool for the optimization of input factors during laser hardening of pure titanium. Chalisgaonkar and Kumar (2013) used utility concept for optimization of cutting speed and surface roughness while machining pure titanium on WEDM. Chakravorty et. al. (2013) applied weighted signal-to-noise ratio (WSN), VlSeKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), utility theory and the multi response signal to noise (MRSN) ratio method for the optimization of EDM parameters. They concluded that WSN and the utility concept method provide better overall optimization results as compared to grey relational analysis (GRA) and other techniques. Rao and Krishna (2013) used PCA method integrated with the Taguchi method for the optimization of WEDM parameters while machining of ZC63/SiCp MMC. Pattnaik et. al. (2013) carried out injection molding of different mixtures of wax and applied utility theory for the optimization of the performances. Goswami and Kumar (2014) optimized WEDM parameters using Taguchi based utility concept approach during processing of Nimonic-80A alloy. Padhi et. al. (2014) applied utility theory in union with Taguchi method for optimization of dimensional deviation (DD) and SR during WEDM of EN-31 steel. Mathew et. al. (2014) used utility approach for the optimization of MRR, SR, and DD while WEDM of AISI 304 steel. Nayak and Mahapatra (2014) carried out taper cutting on AISI 304 steel by applying WEDM. To find out optimal factors.
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