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Material removal rate (MRR) study in the cylindrical wire electrical discharge turning (CWEDT) process

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ABSTRACT

As using wire EDM (WEDM) technology, complicated cuts can made through difficult to machine electrically conductive components, the cylindrical wire electrical discharge turning (CWEDT) process was developed to generate precise cylindrical forms on complicate, hard and difficult to machine materials. A precise, flexible and corrosion resistance submerged rotary spindle was designed and added to a conventional five axis CNC WEDM machine to enable the generation of free-form cylindrical geometries. The hardness and strength of the work material are no longer the dominating factors that affect the tool wear and hinder the machining process. The right selection of machining conditions is the most important aspect to take into consideration in process related to the WEDM operations. This paper presents an investigation on the effects of machining parameters on material removal rate (MRR) in cylindrical wire electrical discharge turning (CWEDT) process. In this research, CWEDT of AISI D3 (DIN X210Cr12) tool steel is studied by using of statistical design of experiment (DOE) method. AISI D3 tool steel was used in the experiments because of its growing range of applications in the field of manufacturing tools, dies and molds as punch, tapping, reaming and so on in cylindrical forms. The effects of EDM parameters such as power, voltage, pulse off time and spindle rotational speed has been analyzed on MRR by using analysis of variance (ANOVA). A model has been developed for MRR by using response surface methodology (RSM). In order to study surface integrity, SEM and micro-hardness tests were carried out in different machining parameters.

1. Introduction

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously traveling wire electrode made of thin copper, brass or tungsten of diameter 0.05–0.3 mm, which is capable of achieving very small corner radii (Ho et al., 2004). During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the workpiece and the wire, eliminating the mechanical stresses during machining. The hardness and strength of the difficult to machine work material are no longer the dominating factors that affect the tool wear and hinder the machining process. This makes the WEDM process particularly suitable for machining hard, difficult to machine materials. In addition, the cutting force in WEDM process is small, which makes it ideal for fabricating miniature parts

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Nomenclature

Adj. MS	adjusted mean squares
Adj. SS	adjusted sum of squares
AD	Anderson–Darling statistic
Coef.	coefficient of factor and factor interaction in the regression model
d.f.	degree of freedom
DOE	design of experiment
F	F-test value
HAZ	heat affected zone
HRC	hardness Rockwell C
HV	hardness Vickers
l	cutting length (mm)
MRR	material removal rate (mm^3/min)
MS	mean squares
P	probability value
r	final radius of machined workpiece (mm)
RPM	spindle rotational speed
R	original radius of workpiece (mm)
R^2	R-squared statistic
R^2_{adj}	adjusted R-squared statistic: correlation coefficient
Ra	surface roughness (μm)
RSM	response surface methodology
S	root mean square
Seq. SS	sequential sum of squares
S.E. Coef.	standard errors for coefficients
SS	sum of squares
t	machining time (min)
T	T-test value
v_f	machine feed rate (machining cutting speed, mm/min)

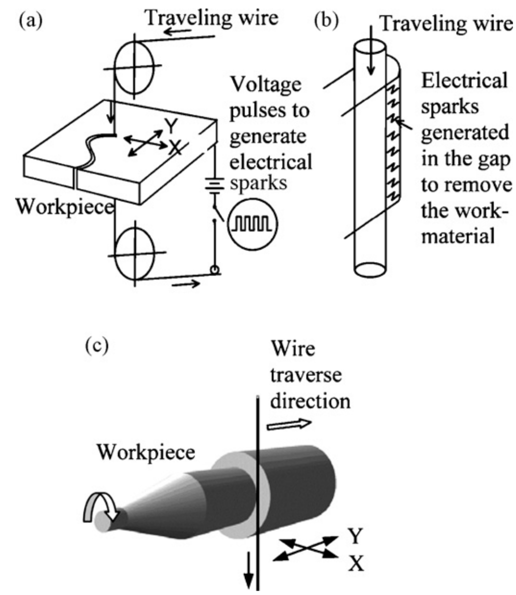

Fig. 1 – Illustration of the conventional and cylindrical wire EDM. (a) Conventional wire EDM, (b) close-up view of the gap and continuous electrical sparks and (c) cylindrical wire EDT.

(Schoth et al., 2005). One of the configurations of WEDM is cylindrical wire electrical discharge turning (CWEDT). The concept of CWEDT is illustrated in Fig. 1. A rotary axis is added to a conventional five axis CNC wire EDM machine in order to produce cylindrical forms. The initial shape of the part needs not to be a cylindrical form. The electrically charged wire is controlled by the X and Y slides to remove the work material and generation of the desired cylindrical form (Qu et al., 2002a,b). Some turning wire EDM works have been reported for manufacturing small pins by Dr. Masuzawa's research group at the University of Tokyo (Masuzawa et al., 1985, 1994; Masuzawa and Tonshoff, 1997). The small diameter pins can be used as tools for 3D micro-EDM application (Qu et al., 2002b). Examples of the machined parts using the CWEDT method have shown in Refs. (Qu et al., 2002a,b; Masuzawa et al., 1985, 1994; Masuzawa and Tonshoff, 1997; Mohammadi et al., 2005). Also, the application of a water-cooled submerged spindle extends the application of WEDM to cylindrical WEDM turning with rotation speed of up to 2800 rpm. This enables the production of gear wheels with integrated shaft for easy gear assembly (Masuzawa et al., 2002). Qu et al. (2002a) derived a mathematical model for the material removal rate (MRR) of the CWEDT process. The same authors (Qu et al., 2002b) investigated the surface integrity and roundness of CWEDT parts using brass and carbide work material. Mohammadi et al. (Mohammadi et al., 2005) investigated the turning by wire electrical discharge machining to evaluate the effects of machining parameters on MRR, surface roughness and roundness by using Taguchi approach. Scott et al. (Scott et al., 1991) used a factorial design requiring a number of experiments to determine the most favorable combination of the WEDM parameters. They found that the discharge current, pulse duration and pulse frequency are the significant control factors affecting the MRR and surface finish, while the wire speed, wire tension and dielectric flow rate have the least effect. Liao et al. (Liao et al., 1997) proposed an approach of determining the parameter settings based on the Taguchi quality design method and the analysis of variance. The results showed that the MRR and surface finish are easily influenced by the table feed rate and pulse on time, which can also be used to control the discharging frequency for the prevention of wire breakage. Huang and Liao (Huang and Liao, 2003) presented the use of grey relational and S/N ratio analysis, which also display similar results demonstrating the influence of table feed and pulse on time on the MRR. An experimental study to determine the MRR and surface finish for varying machining parameters has also been conducted (Rajurkar and Wang, 1993). The results have been used by presenting a thermal model to analyze the wire breakage phenomena. In WEDM operations, MRR determines the economics of machining and rate of production. In setting the machining parameters, the main goal is the maximum MRR. Literature lacks much to say about the use of wire EDM for machining cylindrical forms (CWEDT) of AISI D3 tool steel material, so the need has been felt towards the highlighting of this process with the goal of achieving mathematical models to enhance the process performance. The selection of this material was made taking into account its wide range of application in tools, dies and molds industries as punch, tap-