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An experimental investigation of wire electrical discharge machining of hot-pressed boron carbide

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Abstract

The present work discusses the experimental study on wire-cut electric discharge machining of hot-pressed boron carbide. The effects of machining parameters, such as pulse on time (TON), peak current (IP), flushing pressure (FP) and spark voltage on material removal rate (MRR) and surface roughness (R_a) of the material, have been evaluated. These parameters are found to have an effect on the surface integrity of boron carbide machined samples. Wear rate of brass wire increases with rise in input energy in machining of hot-pressed boron carbide. The surfaces of machined samples were examined using scanning electron microscopy (SEM). The influence of machining parameters on mechanism of MRR and R_a was described. It was demonstrated that higher TON and peak current deteriorate the surface finish of boron carbide samples and result in the formation of large craters, debris and micro cracks. The generation of spherical particles was noticed and it was attributed to surface tension of molten material. Macro-ridges were also observed on the surface due to protrusion of molten material at higher discharge energy levels.

Keywords: Hot-pressed boron carbide; MRR; R_a; Wire electrical discharge machining

1. Introduction

Wire electrical discharge machining (WEDM) of hot-pressed boron carbide is considered in this work. Hot-pressed boron carbide possesses superior hardness, high Young's modulus and low density. Due to the excellent properties, it is a promising material as personnel body armour. This material is used to fabricatea variety of armourpanels to provide ballistic protection against different threats. This material cannot be processed by conventional metal cutting techniques like turning and milling due to its high hardness and strength levels [1,2]. Wire electrical discharge machining a type of unconventional machining process, is employed to accomplish the objective. WEDM plays significant role in cutting the electrically conductive materials to produce intricate profiles and complex shapes. The material removal takes place due to melting and evaporation of workpiece because of the heat produced by discharges. The wire traverse is regulated by numerically controlled system to accomplish the desired accuracy of components.

The most significant performance measures of WEDM are material removal rate (MRR) and surface roughness (R_a) of workpiece. Spark gap voltage, discharge current, pulse on-time, pulse off-time and dielectric flushing conditions are the machining parameters that influence the performance measures. Tosun et al. [1] investigated the effect of WEDM machining parameters on performance characteristics, i.e MRR, kerf width and R_a. An optimum combination of process parameters was derived for large MRR and small R_a by using analysis of variance (ANOVA). Poros et al. [2] made an attempt to develop a model to correlate the thermal properties of material and the efficiency of machining. Buckingham pi theorem was employed to establish the relationship between the variables used in the study. Tzeng et al. [3] studied the influences of cutting speed, depth of cut and feed rate on

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surface roughness using the Taguchi technique and grey relational analysis. In this study, an orthogonal array was applied to plan the experiments for optimizing the cutting operations with multiple response measures. Chiang et al. [4] carried out grey relational analysis to optimize the wire-EDM process with multiresponse characteristics such as MRR and R_a. The optimum process parameters were selected from the response graph obtained by grey relational grade. Kumar et al. [5] employed a grey relational methodology to optimize the input parameters of EDM, i.e., duty factor, pulse on-time and peak current to maximize MRR. The optimum process parameters were validated by confirmation experiments. Wang et al. [6] explored the possibility of removing a recast layer using etching by means of EDM. An L9 orthogonal array was selected to design the experiments for attaining the optimum process parameters. Somasekhar et al. [7] presented the modelling and optimization of micro-EDM using back propagation and genetic algorithms. The neural network model has been established and simulated using MATLAB. Lin et al. [8] attempted to improve the multiple response characteristics using Taguchi technique with grey relational analysis by optimizing the process parameters of EDM. Patel et al. [9] developed a surface roughness prediction model for electric discharge machining of Al_2O_3/SiC/TiC ceramic composite. This model optimized the machining variables to obtain high surface quality. Lin et al. [10] studied the effects of EDM parameters on material removal rate, electrode wear rate and surface roughness for ceramics (Al_2O_3+ 30% VolTiC). Machining parameters have been optimized for each performance measure by using Taguchi method.

The purpose of the present study is to examine the effects of machining parameters on material removal rate (MRR) and surface roughness (R_a) of hot-pressed boron carbide. The material removal rate (MRR) can be considered as the degree of production whereas surface roughness (R_a) represents the measure of surface quality. Based on the literature survey, several pilot experiments have been performed to select the process parameters influencing on performance characteristics. The chosen machining variables are pulse on-time, pulse off-time, peak current and spark voltage. The Taguchi technique is a dominant experimental planning tool that uses an efficient and orderly approach for obtaining the optimum process variables. An appropriate design of experiments (DOE) is selected to perform more precise and accurate experiments. In the present research, an L16 Taguchi standard orthogonal array was selected for the design of experiments [11]. Confirmation experiments were then conducted based on the Taguchi analysis. The surfaces of machined samples were examined using scanning electron microscopy (SEM). The influences of machining parameters on mechanism of MRR and R_a were described.

2. Experimental details

2.1. Material and methods

The experiments were performed using a CNC ULTRACUT WEDM (maker: Electronica Machine Tools Ltd). The wire cut electric discharge machine consists of a machine tool, a CNC pulse generator and a dielectric fluid supply unit. The tool consists of a main worktable, an auxiliary table and a wire drive mechanism [12]. CuZn37 brass wire with 0.25 mm in diameter was employed in the present trials. Wire travels through the workpiece from upper and lower wire guides. In wire-cut EDM process the spark is generated between continuous travelling wire and workpiece. Hot-pressed boron carbide blocks (100 mm × 100 mm × 5 mm thickness) were used. The strength of the material is 410 GPa, its hardness is 31 GPa, and the Young's modulus is 460 GPa. Machining performance was evaluated by MRR and SR.

The MRR was determined by equation

$$MRR(\mathrm{mm}^3/\mathrm{min}) = V_c \times b \times h \qquad (1)$$

where V_c is the cutting rate; b is width of the cut; and h is the depth of the job (mm).

The surface roughness, usually expressed as R_a value in microns, was obtained by Taylor Hobson Surtronic 25 roughness checker.

2.2. Taguchi method: planning of experiments

To study the effects of machining parameters on the performance characteristics (MRR and R_a) under the optimal machining parameters, a specifically designed experimental procedure is required [13−16]. Based on the preliminary investigations, the input parameters chosen were pulse on-time (TON), peak current (IP) and spark voltage (SV). The working range of input parameters and the levels taken are shown in Table 1.

In this study, the Taguchi method, a powerful tool for parameter design of performance characteristics, was used to optimize the machining parameters for maximum metal removal rate, maximum gap current and minimum surface roughness in WEDM [1]. Two major tools used in this method are (i) S/N (signal/noise) ratio to measure the quality and (ii) orthogonal array to accommodate many factors affecting simultaneously to evaluate the machining performances. According to Taguchi quality design concept, an L16 orthogonal array table with 16 rows was chosen for the experiments (Table 2). The experimental observations are further transformed into a signal-to-noise (S/N) ratio by using ANOVA.

The analysis of variance (ANOVA) of S/N data (Tables 3(a) and 3(b)) is carried out to identify the significant variables and quantify their effects on the response characteristics. In the present study, all designs, plots and analysis were carried out using Minitab statistical software. There are several S/N ratios

Table 1
Input process parameters and their levels.

Parameters	Level 1	Level 2	Level 3	Level 4
TON/μs	0.65	0.7	0.75	0.8
IP/A	12	14	16	18
SV/V	10	15	20	25