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Short Communication

Influence of workpiece hardness on EDM performance

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ABSTRACT

The aim of this research is to show the influence of the hardness of the alloy steel on the material removal rate and on the workpiece surface roughness.

The Taguchi methodology was used to study that influence. The result of the verification test for workpiece surface roughness was a strong confirmation. This type of outcome allows the use of the additive model to predict the workpiece surface roughness with an average error of 0.4%.

The result of the verification test for material removal rate was a poor confirmation due to an interaction of parameters. This type of outcome does not allow the additive model to predict the material removal rate with accuracy. Therefore, a linear regression model was developed for material removal rate using workpiece hardness and its interactions, among other variables. This model predicts the material removal rate with an average error of 1.06%.

These results show that workpiece hardness and its interactions have influence on the material removal rate and on the workpiece surface roughness.

1. Introduction

Electrical discharge machining (EDM) is a non-traditional manufacturing process where the material is removed by a succession of electrical discharges, which occur between the electrode and the workpiece. These are submersed in a dielectric liquid such as kerosene or deionised water. The electrical discharge machining process is widely used in the aerospace, automobile and moulds industries to machine hard metals and its alloys.

During the electrical discharge, a discharge channel is created where the temperature reaches approximately 12,000 °C [1], removing material by evaporation and melting [2–4] from both the electrode and the workpiece. When the discharge ceases there is a high cooling on the surface of the workpiece creating a zone affected by the heat that contains the white layer. This layer contains several hollows, spheroids, fissures and micro fissures. Carbon is the main element of the white layer composition influencing simultaneously its hardness and thermal conductivity [5]. The white layer thickness depends on the workpiece material, on the power used to cut the workpiece and on the applied electrical polarity.

Electrical discharge machining is governed by a thermal phenomenon [6,7], therefore not only removes material from the workpiece but also changes the metallurgical constituents in the zone affected by the heat. Thus, during machining by EDM the surface of the workpiece is submitted to a heat treatment (locally), where the time of stage is the pulse duration and the temperature reached by the workpiece is due to the applied current intensity being followed by a quick cooling of the workpiece. These variables affect the metallurgic constituent of the white layer and consequently its hardness [8–10] and its thermal conductivity.

It is also known that during the cut by EDM the material removal rate (MRR) decreases, which is due to process instability according to [11]. However, the decrease of material removal rate is due to the change of metallurgic constituent in the zone affected by the heat, according to the authors. Therefore, the authors have decided to investigate the effect of the initial workpiece hardness on the material removal rate and workpiece surface roughness.

2. Experimental methodology

The effect of the workpiece hardness on the material removal rate and workpiece surface roughness was studied using the Taguchi method, which is generally applied to improve the quality of a product. The Taguchi method is mainly used to optimise a single output. However, some authors [12] use the orthogonal array L_{18} and the grey relational analysis to optimise various outputs simultaneously. The authors used the orthogonal array L_{18}, the analysis of variance (ANOVA), additive model and linear regression to understand the relationship between various inputs and a single output.

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Nomenclature

Ram speed (mm/min) speed at which the ram lifts off the electrode from the workpiece at regular intervals of time

Ram cycle (s) interval of time between lift-offs

Compression (%) degree of deterioration (number of eroded particles during EDM) in the gap

According to Taguchi, "it is desirable to treat the interactions including these in the noise, which is not generally done. Only a main effect that exceeds the value of interactions can be used safely in robust project." Thus, the orthogonal array L_{18} should be used because this array has the property of distributing interactions to all the columns and treats the interactions as equivalent to noise. This array can handle seven parameters at three levels and one parameter at two levels and defines eighteen individual experiments. If all combinations of parameters and levels were used, 4374 ($2^1 \times 3^7$) experiments would be involved, and thus, there is a significant reduction in the number of experiments performed and thereby a significant reduction in cost and time.

This methodology was designed and performed in a die-sinking EDM machine, AGIE COMPACT 3, equipped with adaptive control facilities. The adaptive control optimization (ACO) system enables the process to be optimised automatically and it was switched off so that the results can be generalized to all machines. The electrode and workpiece materials are electrolytic copper and steel AISI/SAE-D2, respectively. Two steel AISI/SAE-D2 bars were used in the research. One bar was quenched and tempered yielding a hardness of 60 HRC; the hardness of the normalized bar was 235 HB. The treated bar and the normalized bar were parallelepipeds with dimensions of $300 \times 60 \times 25\,mm^3$. The electrodes used were copper rods 16 mm in diameter and a length of 160 mm. The EDM performance is related to the efficiency which is determined in the EDM process by the material removal rate and by the electrode wear ratio (EWR). Quality is determined by the accuracy and the surface roughness—only the latter will be considered here. Surface roughness was characterised using the arithmetic average roughness (R_a) value. This was measured using a Hommelewerk T4000 measurement instrument.

This experimental methodology enables the workpiece hardness and its interactions to be significant contributors to the material removed rate and also the workpiece surface roughness to be determined.

3. Experimental results

The importance of the input parameters in the EDM process was determined. There are eight input parameters (Table 1) that affect the EDM performance. Some of these parameters are likely to have a more significant effect on electrical discharge machining performance than others. The levels of the input parameters, *S*1–*S*8, were allocated using the values of rough cut of EDM, given in the AGIE manual. These values are indicated in Table 1. The experimental results of each setting of input parameters of the orthogonal array L_{18} are given in Table 1. These are the average of two experiments.

3.1. Effect of the workpiece hardness on the material removal rate

3.1.1. Analysis of variance

The results of the analysis of variance show that the most significant contributors to the material removal rate are current intensity, duty factor, compression and ram cycle with degrees of significance greater or equal to 90%. The pooling of the small variances [variance ratio lesser or equal to 2%] increases not only the variance error of the overall average but also the degrees of significance of the most important contributors. The results of the pooling of the small variances show that the most significant contributors to the material removal rate are current intensity (17%), duty factor (14%), compression (16%), ram cycle (33%) and pulse duration (9%) with degrees of significance greater or equal to 97.5%. The variance error attributed to unknown sources in obtaining the maximum material removal rate is 10%. These results can be seen in Table 2.

Nevertheless, the two bars have significantly different workpiece hardness, the material removal rate decreases slightly. It is important to point out that the interactions of parameters were not studied because the orthogonal array has the property of

Table 1
Orthogonal array L_{18} and experimental data.

Number of trials	Steel hardness (*S*1)	Current intensity NC (*S*2)	Applied voltage NC (*S*3)	Pulse duration NC (*S*4)	Duty factor % (*S*5)	Ram speed mm/min (*S*6)	Compression % (*S*7)	Ram cycle s (*S*8)	MRR (ave.), mm^3/min	Ra (ave.), μm
1	1(235 HB)	10	2	16	50	350	20	0.3	2.89	7.1
2	1	10	4	18	65	525	30	2	17.66	7.7
3	1	10	6	19	80	700	40	30	27.82	7.2
4	1	11	2	16	65	525	40	30	33.90	7.6
5	1	11	4	18	80	700	20	0.3	11.40	9
6	1	11	6	19	50	350	30	2	16.92	9
7	1	12	2	18	50	700	30	30	30.80	10.8
8	1	12	4	19	65	350	40	0.3	13.24	10.8
9	1	12	6	16	80	525	20	2	31.32	9.5
10	2(60 HRC)	10	2	19	80	525	30	0.3	7.62	7.3
11	2	10	4	16	50	700	40	2	22.05	6.5
12	2	10	6	18	65	350	20	30	5.68	8.6
13	2	11	2	18	80	350	40	2	34.95	9.2
14	2	11	4	19	50	525	20	30	7.93	9.7
15	2	11	6	16	65	700	30	0.3	14.03	7.4
16	2	12	2	19	65	700	20	2	21.81	11
17	2	12	4	16	80	350	30	30	43.68	9.2
18	2	12	6	18	50	525	40	0.3	14.54	11.8