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Study of surface integrity and dimensional accuracy in EDM using Fuzzy TOPSIS and sensitivity analysis

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ABSTRACT

Surface integrity and dimensional accuracy remain critical concern in Electrical Discharge Machining (EDM). The current research work aims at investigating the influence of various EDM process parameters like pulse current (*Ip*), pulse-on time (T_{on}), tool work time (T_w) and tool lift time (T_{up}) on various aspects of surface integrity like white layer thickness (WLT), surface crack density (SCD) and surface roughness (SR). The dimensional accuracy, characterized by over cut (OC), has also been studied in the similar way. A response surface methodology (RSM) – based design of experiment has been considered for this purpose. The present study also recommends an optimal setting of EDM process parameters with an aim to improve surface integrity aspects after EDM of AISI P20 tool steel. This has been achieved by simultaneous optimization of multiple attributes (i.e. WLT, SCD, SR and OC) using Fuzzy-TOPSIS-based multi-criteria decision making (MCDM) approach. The optimal solution was obtained based on five decision makers' preferences on the four responses (i.e. WLT, SCD, SR, and OC). From this analysis, an optimal condition of process parameters of Ip = 1 A, T_{on} = 10 µs, T_w = 0.2 s, and T_{up} = 1.5 s has been determined. Furthermore, sensitivity analysis was also carried out to study the sensitivity or robustness of five decision makers' preference of optimal machining parameters. Form this study, decision makers' preference for surface crack density has been found to be the most sensitive response and therefore should be chosen first and analyzed very carefully.

1. Introduction

Electrical Discharge Machining (EDM) is an erosion process, whereby rapidly recurring spark is generated between the tool and the workpiece in order to remove the materials form the later. EDM is the one of the most versatile non-conventional machining processes since the effectiveness of EDM process is absolutely independent of mechanical properties of the workpiece material. Therefore, very hard and difficult-to-cut materials can be effectively machined into desired complex shape, if the work piece materials are electrically conductive. During the process of EDM, material removal takes place due to melting and vaporization from the localized zone of the workpiece. Thermal energy liberated during EDM due to generation of spark leads to formation of thermally affected layers on the machined surface. The properties of such layers are different from parent workpiece material [1]. Therefore, surface integrity in EDM is an issue which requires considerable research attention. Surface integrity in EDM is usually characterized by surface roughness, formation of recast layer or white layer and surface cracks, residual stress and metallurgical modification of parent material [2]. Therefore, if the surface integrity is not adequately addressed, the EDMed component would be more prone

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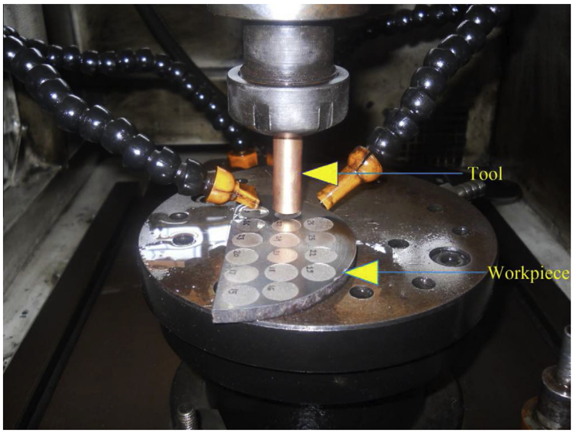

Fig. 1. Experimental setup.

Table 1
Machining parameters and their levels.

Parameters	Symbol	Level			Unit
		1	2	3	
Control parameters					
Pulse current	*Ip*	1	3	5	A
Pulse on Time	T_{on}	10	80	150	μs
Tool work time	T_w	0.2	0.6	1.0	s
Tool lift time	T_{up}	0.0	0.75	1.5	s
Fixed parameters					
Duty cycle	ζ	70			%
Voltage	*V*	45			V
Flashing pressure	*Fp*	0.3			Kg f/cm^2
Sensitivity	SEN	6			
Inter electrode gap	IEG	90			μm

to failure during its intended application. Surface finish in EDM attracted significant research interest. Different mathematical models have been developed to correlate surface roughness with various EDM parameters like discharge current (*Ip*), pulse-on time (T_{on}), pulse-off time (T_{off}), duty cycle (T_{au}), polarity, input power, and thermal physical and electrical properties of workpiece and tool [3,4]. It has been found that process parameters like *Ip* and T_{on} played a major role in influencing EDMed surface roughness. For better surface finish, *Ip* and T_{on} should preferably be low [5,6]. Effect of EDM parameters on white layer and surface crack formation for D2 and H13 tool steel was studied by Lee and Tai [7]. It was observed that white layer thickness (WLT) and induced residual stress appeared to increase at higher value of *Ip* and T_{on}. Cracks found on the transverse plane of machined component was quantified it terms of surface crack density (SCD) which increased at lower *Ip* and decreased as T_{on} was increased. Similar observation was also made on AISI 1045 steel [8] and AISI D2 tool steel [1]. Pradhan [9] determined optimal setting of EDM parameters using RSM combined with grey relation analysis (GRA) as multi-objective optimization technique with an aim to achieve improved surface integrity during EDM of AISI D2 tool steel.

Table 2
Linguistic variable for the important weight of each output.

Fuzzy subset	Respected fuzzy weight
Tiny (T)	(0.000, 0.000, 0.0769, 0.1538)
Very Small (VS)	(0.0769, 0.1538, 0.2307, 0.3076)
Small (S)	(0.2307, 0.3076, 0.3845, 0.4612)
Medium (M)	(0.3845, 0.4614, 0.5383, 0.6152)
Large (L)	(0.5383, 0.6152, 0.6921, 0.7690)
Very Large (VL)	(0.6921, 0.7690, 0.8459, 0.9228)
Huge (H)	(0.8459, 0.9228, 1.000, 1.000)

Another issue of concern during EDM is overcut phenomenon due to sparking from lateral surface or corner of bottom surface of the tool electrode. This leads to dimensional inaccuracy of EDMed component. Pulse current and pulse-on time have been found to be major parameters in influencing overcut. Increase in both *Ip* and T_{on} resulted in rise in overcut [10–12] owing to higher amount of discharge energy associated with them. However, inverse relationship between *Ip* and overcut has also been reported during micro-EDM of Ti–6Al–4V alloy [13].

It is evident that EDM is always characterized by multiple output responses. Therefore, multi-objective optimization has become one of the major areas of research in EDM for determining optimal process condition. In the recent years, fuzzy logic-based multi-criteria decision making approaches have become very popular in optimization of different manufacturing processes. Sivapirakasam et al. [14] applied Fuzzy-TOPSIS technique to optimize various responses like process time, relative electrode wear rate, process energy and consumption of dielectric fluid during EDM of tool steel. Grey-fuzzy logic-based optimization technique was utilized to optimize MRR, TWR and SR during EDM of SKD11 alloy steel [15]. Puhan et al. [16] integrated principal component analysis (PCA) and fuzzy inference system coupled with Taguchi method to find out optimal condition of EDM parameters.

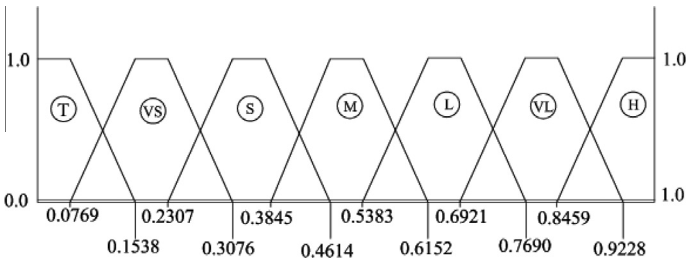

Fig. 2. Membership function of responses.