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Parameter Optimization by using Grey Relational Analysis of Photochemical Machining

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Abstract: *Photochemical machining (PCM) is one of the least well-known nonconventional machining processes. The measure of performance is undercut (Ud), material removal rate (MRR) and surface roughness. In this paper, Response surface method technique and grey relation method for optimization of the process parameters in SS316L steel etching of PCM process were used for the prediction of Material Removal Rate (MRR), Surface roughness (Ra) and undercut (Ud). The data used for prediction, derived from experiments conducted in etching operation of PCM process according to the principles of Design of Experiment (DoE) method. The input factors considered in the experiments were time, temperature, and concentration of etching process where SS16L steel was used as substrate. The optimum values of input parameter by gray relation analysis are temperature 65°C, time 45 minute and concentration 750 gm/litre. The optimum material removal rate was 0.219 mm^3/min, surface roughness was 0.867 µm and undercut 0.095 mm in grey relational respectively.*

Keyword: PCM, Grey relational analysis, RSM, undercut, MRR, DOE.

1. INTRODUCTION

Photochemical machining (PCM) is non-conventional machining processes which produce burr free and stress free flat complex metal components (D.M. Allen et. al, 2004). It is controlled dissolution of work-piece material by contact of strong chemical solution without changing chemical and mechanical properties of work piece material. It is useful for components with relatively low geometric complexity and high feature size. It employs chemical etching through a photo-resist stencil as method of material removal over selected areas. Therefore, it is very important that the proper selection of PCM process parameter to improve product quality. In this, paper the use of grey-based method to optimize the PCM process parameter with consideration of input parameters etching time, etching temperature and etchant concentration with multiple output parameters such as MRR, Ra Undercut is reported. The RSM method is a systematic application of design and analysis of experiment for improving of product quality. The grey relational analysis is a multiple performance characteristics the optimization of process parameters. The grey relational theory converts a multiple response process optimization problem into a single response optimization using maximization of overall grey relational grade (J.L. Lin, 2002).

The grey rational theory has been successfully used in various fields, including industry, agriculture, economics and engineering. It can be successfully used to solve problems that are uncertain or which involve systems with incomplete information (Tong et al., 2006). David et al. (2004) has studied Characterization of aqueous ferric chloride etchants used in industrial photochemical machining. $Fecl_3$ most commonly used as etchants for ferrous material. But there is wide variety in grades of $Fecl_3$.$Cucl_3$is generally used for etching of copper material. Defining standards for industrial etchants and methods to analyze and monitor them Rajkumar et al. (2004) have investigated the Cost of photochemical machining in which they gave application of electrolytic Photo polishing and stated the two methods for manufacturing of edge filter Professor David et al. (2004) gave the PCM as the state of the art, the PCM Roadmap and its examples. David et al. (1983) gave the surface textures and process characteristics of the electrolytic photo etching of annealed AlSl 304 stainless steel in hydrochloric acid. As observed from past literature, no systematic study has been reported so far to analyze the interaction effects of process parameters on etching process of PCM. It depends on experience of operator and optimal set of parameter required for process is not calculated, it is taken only by experience. The study is necessary to investigate the performance in different ranges, and to find the global optimum parameters. It is necessary to find out single optimum parameters setting to satisfy the requirements of excellent etching quality as per the application. In this paper attempt is made to finalize optimum parameters grey relational analysis.

2 DESIGN OF EXPERIMENTS

In this study, experiments were designed on the basis of the experimental design technique which refers to the planning of experiments, collection and analysis of data with near-optimum use of available resource (D.C.Montgomery). It is an experimental method designed and developed for evaluating the effects of process parameters on performance characteristics. It determines the process parameter conditions for optimum response variables. During experimentation, a large number of experiments have to be carried out as the number of machining parameters increases. Design of experiments involves proper selection of variables (input factors) and their interactions. The use of statistically derived centre composite design gives the number of experimental runs, to be carried out without affecting the quality of the analysis. Therefore, the centre composite design method was used to determine optimal machining parameters for maximum material removal rate and minimum undercut with less etching time. The centre composite design consists of all combinations of the input parameters taking on three levels. These are high, medium and low levels of factors. Accordingly to centre composite design 20 experiments were planned as per the selected design with one replication. The present investigation studied the results of the effects of Concentration, Time and Temperature on the volumetric metal removal rate, surface roughness and undercut during the PCM process of SS316L material. Input parameters and their levels are shown in Table 1.Table 2 shows experimental design matrix with coded and un-coded values of 20 centre composite design.

Table1. Input parameters and their levels

Factor/coding	Notation	(-1)	(0)	(+1)
Time (min)	t	30	45	60
Temperature (^{0}C)	T	50	65	80
Concentration (gm/lit)	C	600	750	900

Table 2 Experimental layout plan for centre composite design of experiments (CCD)

Run order	Time (min)	Temperature (^{0}C)	Concentration (gm/lit)
1	-1	-1	-1
2	0	0	0
3	0	0	0
4	1	0	0
5	-1	0	0
6	-1	-1	1
7	-1	1	1
8	1	-1	1
9	1	1	1
10	0	1	0
11	0	0	-1
12	0	0	0
13	0	-1	0
14	-1	1	-1
15	1	-1	-1
16	0	0	1
17	0	0	0
18	0	0	0
19	0	0	0
20	1	1	-1

3 EXPERIMENTAL PROCEDURE

In PCM process first step is engineering drawing or sketch that defines the precise characteristics of final part .The AUTOCAD system and laser plot technology are to be utilizing to generate an exact image of final part on a set of photographic films, which is known as Photo-tool. The Photo-tool is used to transfer the images of final part photographically on a clean sheet of flat metal as it is made of transparent paper. The flat metal should coat with photo-resist which is

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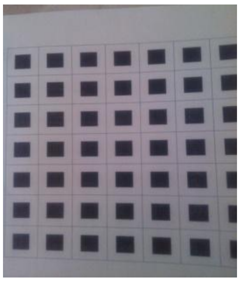
photosensitive, etchant-resistant polymer on both side. The coating is done on only on that part opposite to film. Then the specimen is UV exposed. The result of this process is a final component as per image on sheet of metal. The machining is done on that part which is not covered with photo-resist. The sheet is then dip in a heated etching solution. The metal not covered by the photo-resist is dissolved, leaving precisely. Metal with exposed and developed photo resist Metal etched nominal dimensions. The SS316L steel with chemical composition Carbon 0.03 %, Chromium 16.00 - 18.00%,Molybdenum 2.00-3.00 %, Sulphur 0.03 %, Phosphorus 0.045%, Nickel 10.00 - 14.00%, Manganese 2.00%, Silicon 0.75% was selected for experimentation. The thickness of specimen was 2mm and cut at 20mmX20mm dimension. $FeCl_3$ chemical etchant was prepared at 3.76M. The amount of etchant for each experiment was 100ml. Single sided chemical etching was conducted. The measurements of thickness were carried out by mitutoyo micrometer (± 0.001 mm) and for Ra measurement TIME made roughness tester is used .Undercut is determined by using Rapid-I machine. Fig 1 shows schematic representation and photo of experimental setup.

a) Material before machining



b) Square Phototool

c) Photoresist Solution

d) UV Exposure Unit

e)Chemical etching

d) Finished Part

Fig. 1. Experimental Setup Of Photochemical Machining

4 RESULTS AND DISCUSSION

Grey relational analysis ranks the experiments based on the increasing order of their grey relational grade(GRG). The present investigation is focused on the improvement of maximum material removal rate and minimum undercut and surface roughness in PCM process. From GRC values of MRR, Ra and UC, grey relational grade (GRG) is obtained. The GRG values for all twenty experiments are show in Table 3.

Table 3 GRG calculation

Sr. No.	Grey Relational Coefficients			Grey Relational Grade
	$\xi_i(1)$	$\xi_i(2)$	$\xi_i(3)$	γ_i
1	0.353	0.486	0.529	0.456
2	0.826	0.334	0.336	0.499
3	0.950	0.971	0.988	0.970
4	0.496	0.593	0.707	0.599
5	0.496	0.450	1.000	0.649
6	0.403	0.584	0.918	0.635
7	0.359	0.474	0.698	0.510
8	0.488	0.648	0.859	0.665
9	0.990	0.826	0.829	0.882
10	0.538	0.652	0.781	0.657
11	0.871	0.899	0.856	0.875
12	0.962	0.994	0.989	**0.981**
13	0.747	0.882	0.846	0.825
14	0.434	0.621	0.989	0.681
15	0.352	0.484	0.621	0.486
16	0.595	0.645	0.511	0.584

17	1.000	0.971	0.818	0.930
18	0.877	0.911	0.978	0.922
19	0.984	1.000	0.902	0.962
20	0.530	0.541	0.519	0.530

Condition twelve is optimum at Temperature =65°C, Concentration=750 gm/litre, and Time=45 minute. According to the experiment design, it is clearly observed from Table 3that the PCM process parameter setting of experiment no.12 has the highest grey relational grade. Therefore, experiment no.12 is the optimal process parameters setting for maximum material removal rate (MRR), minimum roughness and minimum undercut (UC) simultaneously (i.e. the best multi-performance characteristics) among the twenty experiments. In other words, the optimum condition for PCM performance for both material removal rate (MRR) and undercut (UC)) was found for Temperature =65°C (level-0), Concentration=750 gm/litter (level-0), and Time=45 minute (level-0) combination. As listed in Table 4, the difference between the maximum and the minimum value of the grey relational grade of the photochemical machining parameters is as follow: 0.234 for time, 0.184 for temperature and 0.193 for concentration.

Table 4 Response table for grey relational grade

Level	Time	Temperature	Concentration
1	0.586	0.613	0.606
2	0.82	0.797	0.799
3	0.632	0.652	0.655
Max - Min	0.234	0.184	0.193

The most significant factors affecting PCM performance characteristics are determined by comparing thesevalues. This comparison will give the level of significance of the input factors over the multi-performancecharacteristics. The most effective controllable factor was the maximum of these values. Here, the maximum value among 0.234, 0.184 and 0.193 is 0.234. The value indicates that the time has the strongest effect on the multi-performance characteristics among the selected PCM process parameters. On the other hand, the significant role of every input factor can be obtained by examining these values. The order of importance of the controllable factors to the multi-performance characteristics in the PCM process, in sequence can be listed as: factor A (time), C (concentration) and B (temperature), (i.e. 0.234>0.193 > 0.184). The factor time (0.234) was the most effective factor to the performance of the PCM process.

The main effects plots for grey relational grade Fig. 2.. In this study, Taguchi grey relational analysis was employed to optimize the PCM process parameters for multi-performance characteristics that include material removal rate, surface roughness and undercut in copper etching.

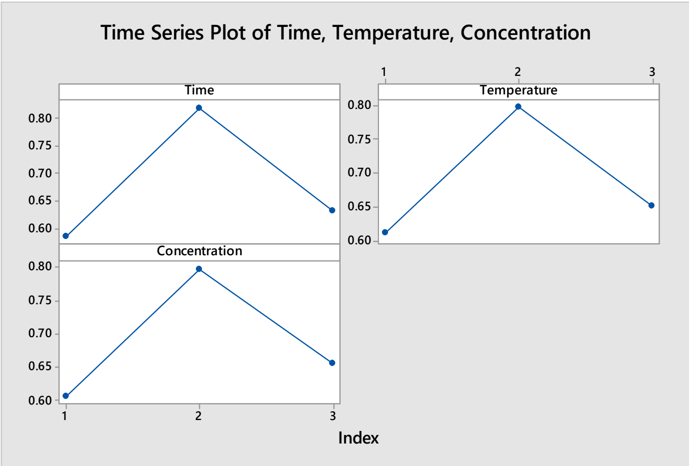


Fig. 2 Main effect plots for grey relational grade

It is found that the largest value of grey relational grade which corresponds to better process performance was obtained for the following parameter combination: Temperature 65°C, Concentration 750gm/litre and Time .45 minute. The main effect plot shows that time and temperature has linear dependence on the variation in grey relational grade value. The first higher contribution is time increases from 30 to 45 min; there is a sudden increase in the GRG value from 0.586 to 0.82. The second higher contribution is concentration increases from 600 to 750gm/lit the GRG values increase from 0.60 to 0.79 and from 750 to 900 gm/lit the GRG values slightly decreases from 0.79 to 0.655. The temperature has less contribution to the variability of GRG over the selected range. As the temperature increases from 50°C to 65°C, there is a significant increase in the

GRG value from 0.61 to 0.79 and from 65°C to 80°C there is slight change in GRG value from 0.79 to 0.65. These values are the recommended levels of input machining parameters that gives the optimum value of multi-performance characteristics. The most influential factor observed from the graph is time. The order of importance of the input factors to the multi-performance characteristics is time, concentration and temperature. Experimental results have shown that the material removal rate, Ra and undercut in photochemical machining of SS316L can be improved effectively through the proposed approach. This study indicated that the grey relational analysis approach is a robust way to obtain optimal parameters from the multiple quality characteristics.

5 CONCLUSIONS

The gray-based Taguchi method is used to determine the optimal input parameter levels of photo chemical machining of SS316L with the multi-performance characteristics has been given in this paper. A gray relational analysis gives the single performance characteristic for MRR, Ra and UC in terms of grey relational grade.

1 The conditions of experiment number twelve, Temperature at 65°C, Concentration 750gm/litre, and Time 45 minute is optimum for MRR, Ra and UC.

2 The time has the most effecting parameter in photochemical machining of SS316L amongst the selected process parameters.

3 The order of importance of controllable factors effecting multi-performance characteristics in the photochemical machining of SS316L steel are in sequence can be listed as: factor A (time), C (concentration), B (temperature) and, (i.e. 0.234>0.193 > 0.184).

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