# OPTIMIZATION OF PROCESS PARAMETERS IN ETCHING DURING PHOTO CHEMICAL MACHINING PROCESS

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## Abstract

Photochemical machining (PCM) is one of the non-conventional machining processes. It is necessary to find out single optimum parameters setting to satisfy the requirements of excellent etching quality. There is need to study combine effect of all other parameters on etching. The measure of performance were material removal rate, etch factor and undercut. In the present study an attempt is made to optimize photochemical machining process parameters by using Design of Experiments by using copper as substrate and ferric chloride as etchant. An optimal parameter combination for maximum material removal rate and undercut within the range selected control parameters were obtained by using analysis of variance (ANOVA) and F-Test. It was observed that, the optimal parameter for the maximum material removal rate, etch factor and undercut is at etchant temperature $60^{o}$ C, concentration of etchant 700 gm/lit and time of etching 5 min. As per the results it was observed that, etchant temperature, concentration of etchant and time of etching are the significant factors for the material removal rate and undercut. The material removal rate ranged from 0.050 to 0.393 $mm^3$/lit. and undercut 0.002 to 0.24 mm. Results of experiments at optimal setting have confirmed the improvement in the process performance.

***Keywords:*** PCM, Copper, $FeCl_3$ , Etching, undercut, MRR.

## 1. INTRODUCTION

Photochemical machining is an engineering production technique for the manufacture of burr free and stress free flat metal components.

The major steps are:

- Preparation of phototool
- Selection of metal
- Preparation of workpiece
- Masking with photoresists
- Etching
- Stripping and inspection

David M. Allen, Heather J.A. Almond [2], have studied Characterization of aqueous ferric chloride etchants used in industrial photochemical machining. $Fecl_3$ most commonly used as etchants. But there is wide variety in grades of $Fecl_3$. defining standards for industrial etchants and methods to analyze and monitor them Rajkumar Roy et. al. [3] have investigated the Cost of photochemical machining in which they gave the cost model for PCM. The paper identifies the costs involved in photochemical machining and presents a cost model for PCM using a bottom-up approach. D.M. Allen et.

al. [4] have study Manufacture of stainless steel edge filters: an application of electrolytic Photopolishing and stated the two methods for manufacturing of edge filter Professor David M. Allen et al. gave the PCM as the state of the art, the PCM Roadmap and its examples.

Jonathan Muhl et al. [6] have studied Direct printing of etch masks under computer control in which all the stages of photo-processing and mask making. D.M. Allen et al. [7] gave the Surface textures and process characteristics of the electrolytic photoetching of annealed AlSl 304 stainless steel in hydrochloric acid.

From literature review it concluded that PCM process depends on experience of operator and optimal set of parameter required for process is not calculated, it is taken only by experience. In this paper attempt is made to finalize optimum parameters by ANOVA method.

## 2. Experimental Procedure

During experimentation the time of etching, temperature and concentration of etchant is necessarily to be changed. For this heating bath as shown in figure is used which varies temperature from 20 $^0$C to 125 $^0$C. In this heating bath heater is used to change the temperature of water which can be sensed by sensor. In this heated water four beakers can be placed for experimentation. This instrument is used in place of etching machine shown in fig.1. For experimentation Cu component of 20mm x 20mm was taken and Φ9mm hole was machined by PCM process.

### 2.1. Mechanism

PCM process begins from engineering drawing or sketch that defines the precise characteristics of your part. Then utilize CAD system and laser plot technology to generate an exact image of your part on a set of photographic films, called a Photo-tool. Depending upon the size of your part, the Photo-tool may contain from one to several thousand exacting images of your part [24].

The Photo-tool is used to transfer the images of your part photographically to a sheet of clean flat metal which has been coated on both sides with a photosensitive, etchant-resistant polymer called photo-resist. The result of these processes is a sheet of metal that is covered with photo-resist over only that metal that will eventually become your parts. The sheet is then sprayed with a heated etching solution. The metal not covered by the photo-resist is dissolved, leaving precisely the parts that you specified. Metal with exposed and developed photo resist Metal etched nominal dimensions

### 2.2 Requirements for Experimentation

- Material –Copper
- Chemical - $FeCl_3$
- Electric supply (15A/15V-D.C.)
- Digital weight m/c., vernier caliper, micrometer and height gauge.
- Thermometer, Stopwatch
- Stirrer and stand for hanging work-piece
- Small heater, beakers, measuring cylinder tissue paper and water
- Rubber gloves, goggles, plastic bags, jars, plastic trays.
- Liquid photo-resist, photo-resist Thinner, photo-resist Developer, photo-resist Dye

- Lith Film 250mm x 250mm, Lith Film developer, Lith Film fixer
- 1X Contacter – Artwork Negative Maker
- Laminate Coater
- Photo-resist Dryer
- Both side u. v. exposure
- Etching machine

## 2.3 Selection of Etching Parameters

Many parameters affect the performance of PCM process and the setting of these parameters relies strongly on the experience of operator's and the parameter. So the first task is to select a reasonable set of input parameters. On one hand a smaller of parameters might not serve the purpose, but on the other hand a large number of parameters will make the prediction more difficult. Thus, the choice of input parameters is, to some extent, a compromise. Base on the survey of literature, experience of the operators and some preliminary experiments, input parameter were chosen. These input parameters are called as control parameters. These control parameters were varied in a range during the experiments to study their effect on the performance measure. The fixed and variable control parameter and its range are given in Table 1 and Table 2

## 3.4 METHODOLOGY

The objective of this study as discussed earlier is to study the effect of combination of various process parameters on the PCM process performance. A total of three etching parameters were chosen as the controlling factors. Each parameter was designed to have three levels namely small, medium and high denoted by 1, 2 and 3 respectively. (Number of treatment conditions = $3^3 = 27$) Three parameters and three levels are shown in Table 3. The levels of these parameters were selected by doing literature survey [54] and preliminary tests mentioned earlier. During the initial test it was found that as the concentration increases, the time of treatment is reduced.

There are other factors, which can be expected to have an effect on the measures of predominance. In order to minimize their effects, these other factors were held constant. Here three control parameters were considered. For three replicates, the experimental design matrix was same, and the control parameters and their levels also unchanged. The only difference was the conditions under which the experiments were performed. Experimentation was performed according to the flow chart given.

## 4. Results and Discussion

In this method, a loss function is used to calculate the deviation between the experimental value and the desired value. This loss function is further transformed into a mean average response. There are several mean average response available depending upon the types of performance characteristics. In performance characteristics higher value represents better etching performance, such as MRR is called "larger is better, HB". Inversely, the characteristics that lower value represents better etching performance, such as undercut, is called "lower is better, LB". The mean average response could be an effective representation to find the significant parameter from those controlling etching parameters by evaluating the minimum variance.

In PCM, higher material removal rate and was considered as better performance. Therefore, 'HB' for the higher material removal rate and was selected for obtaining optimal etching performance characteristics.

By applying these equations, the average response values of etching performance for all replicates of experimental design matrix can be calculated. The results of all replicates of experimental design matrix for average response values are shown in table material removal rate and undercut. However, it is hard to assure that only these setting will result in best performance because of the small difference of the mean average response values between different levels and experimental error. Hence the optimal combination of parameter can be obtained by the ANOVA. The ANOVA table partitions the variability of the response into separate pieces for each of the effects. It is then tests the statistical significance of each effect by comparing the mean square against an estimate of the experimental error. At 95% confidence level in the present experiment, each effect having p-value less than 0.05 is significant. All the effect having p-value greater than 0.05 are non-significant and they may therefore is eliminated. Thus, the last column in the ANOVA table gives these p-values and there by shows the significance of each effect.

### 4.1 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a statistically based objective decision making tool for detecting any difference in average performance of groups of items tested. The decision rather than using pure judgments, take variation in to account. The experimental design and subsequent analysis like ANOVA are intrinsically tied to each other. Analysis of variance breaks total variation down into accountable sources and total variation is decomposed into its appropriate components.

The *P*- value approach is widely adopted in practice risks implied by specified a value or level of significance. The P - value is a probability that the test statistic will take on a value that is at least as extreme as the observed value of the statistic when the null hypothesis Ho is true. Thus, the P- value conveys much information about the weight of evidence against Ho and so a decision maker can draw a conclusion at any specified level of significance. The P-value is therefore the smallest level of significance that would lead to rejection of the null hypothesis Ho.

#### 4.1.1 The influence of Etching parameter on Undercut

In order to obtain the effect of the etching parameter on etching performance for each different level, the average response of each fixed parameter and level for each etching performance are summed up. Table 4 shows the total average response at the levels of three parameters on undercut. The result shows that the optimum etching performance for the undercut is obtained at temperature of 60 °c, concentration of 800 gm and time of 15 min. This is the optimum setting obtained under the conditions in which the experiments were performed. The undercut increases with increase concentration. The result of ANOVA for the undercut is presented in Table 5. The ANOVA for undercut shows that the effect of all factors namely temperature, concentration and time are significant. According to F-test, temperature and time are the most significant parameters on undercut.

Figs 2 to 4 show the evaluation of undercut as a function of temperature, concentration and time. According to graph, we can evidence that response undercut is increases with increasing in etch concentration, time and temperature. But initially at lower level undercut is very small and it is very high at higher levels. Etching process if prolonged undercut is always going to be more. So etching process to be completed without significant undercut temperature and concentration must be at higher level.

### 4.1.2 The influence of Etching parameter on Material Removal Rate

In order to obtain the effect of the etching parameter on etching performance for each different level, the average response of each fixed parameter and level for each etching performance are summed up. Table 6 shows the total average response at the levels of three parameters on MRR. The result shows that the optimum etching performance for the MRR is obtained at temperature of 60 °c, concentration of 800 gm and time of 15 min. This is the optimum setting obtained under the conditions in which the experiments were performed. The MRR increases with increase concentration. The result of ANOVA for the MRR is presented in Table 7. The ANOVA for undercut reduction shows that the effect of all factors namely temperature, concentration and time are significant. According to F-test, concentration and time are the most significant parameters on MRR.

Figs 5 to 7 show a martial removal rate is high as increasing in temperature and concentration while time is not significant affecting parameter.

This is due to as raising the temperature speeds up the smoothing process. The raise in temperature solution favours the formation of passive film on the surface. At the same time a result of increase the rate of diffusion of the etchant, the rate of dissolution of the film also increases. The etchant reaching metal surface first of all reaches with to film covering the micro asperities which can sequencely dissolve more rapidly than the metal in the micro depression of the metal surface. But in higher temperature working become difficult and pitting takes place and at lower temperature, etching rate slow and uneconomical.

The raise in concentration of etchant favors the etching. But in higher the concentration of etchant undercut is more and at lower temperature, etching rate slow and uneconomical.

Time of etching has considerable effect on undercut and material removal rate but as the concentration of etchant increases, the time of etching is reduced. Through analysis, it has been served that undercut increases with time. This could be due to the balance between film depletion.

## 5. Conclusions

- This work was carried out to study the viability of PCM process on copper substrate and ferric chloride etchant. The material removal rate ranged from 0.050 to 0.393 $mm^3$/min and undercut 0.002 to 0.24 mm. Results of experiments at optimal setting have confirmed the improvement in the process performance.
- The results show that optimal PCM process performances for the material removal rate and undercut is obtained at etchant temperature 60 $^0$C, concentration of etchant 700 gm/lit and time of etching 5 min.
- As temperature varies from 40 $^0$C to 60 $^0$C, increase in the undercut was from 0.008 to 0.040 mm and increase in material removal rate was from 0.03 to 0.047 $mm^3$/min.
- As etchant concentration varies from 600° C to 800° C, increase in the undercut was from 0.022 to 0.040 mm and increase in material removal rate was from 0.22 to 0.040 $mm^3$/min.
- As time varies from 5 min to 15 min, the increase in the undercut was from 0.18 to 0.24 mm and reduction in material removal rate was from 0.52 to 0.35 $mm^3$/min.

- The above discussion confirmed the validity of full factorial methodology for enhancing the etching performance and optimizing the etching parameters. The material removal rate and undercut are greatly improved by this approach.

## References


- Report by Qualitetch Components Ltd, “Photochemical machining (PCM)-An overview”.
- David M. Allen., 2004. “Photochemical Machining: From Manufacturing’s Best Kept secret to a $6 Billion per annum, Rapid Manufacturing Process”, CIRP Journal of Manufacturing Systems 53, 559-573.
- David M. Allen, Heather J.A. Almond., 2004. “Characterization of aqueous ferric chloride etchants used in industrial photochemical machining”, Journal of Materials Processing Technology 149, 238–245.
- Rajkumar Roy, David Allen, Oscar Zamora., 2004. “Cost of photochemical machining”, Journal of Materials Processing Technology 149, 460–465.
- D.M. Allen and T.N. Talib., 1983. “Manufacture of stainless steel edge filters: an application of electrolytic photopolishing”, precision engineering, 57-59.
- G.V. Mahesh and G. Ananda Rao., 1989. “Printed circuit board technology-An Overview”, CEDT, First Edition, 1-32.
- P.J. Davis and G.E. Overturf., 1986. “Chemical machining as a precision material removal process”, precision engineering 8, 67-71.
- D.M. Allen, T.N. Talib and D.F. Hornet., 1983. “Surface textures and process characteristics of the electrolytic photoetching of annealed AISl 304 stainless steel in hydrochloric acid”, precision engineering.
- HMT, “Production Technology”, p.p. 230-234.
- Machining Handbook, Ninth Edition , Volume 16.
- Created by PEI, “Design Guide to Photo Chemical Etching”.
- American Society for Metals Handbook, "Properties and Selection: Stainless Steel, Tool materials”, Ninth Edition, Vol.3, p. 4.
- Douglas C. Montgomery, " Design and Analysis of Experiments”, Fifth Edition, John wiley and sons, INC, 1997.


## Figure

Fig 1 **Set-up for etching**

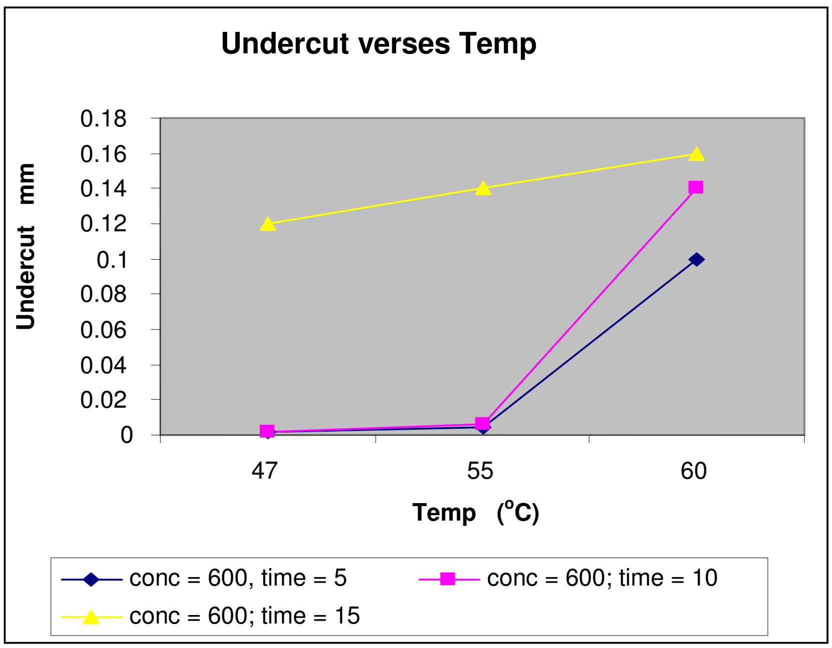


**Fig. 2** Graph of Undercut verses Temp

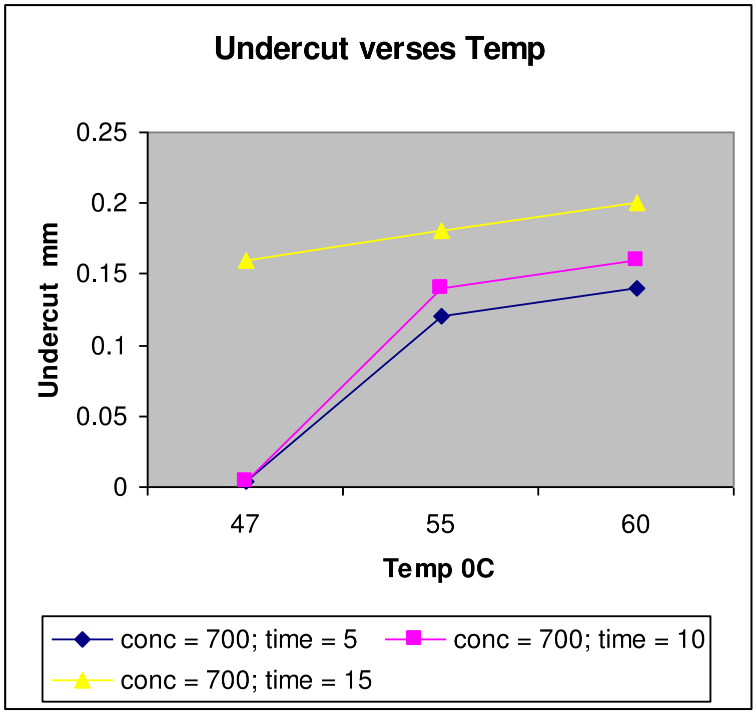


**Fig. 3** Graph of Undercut verses Temp

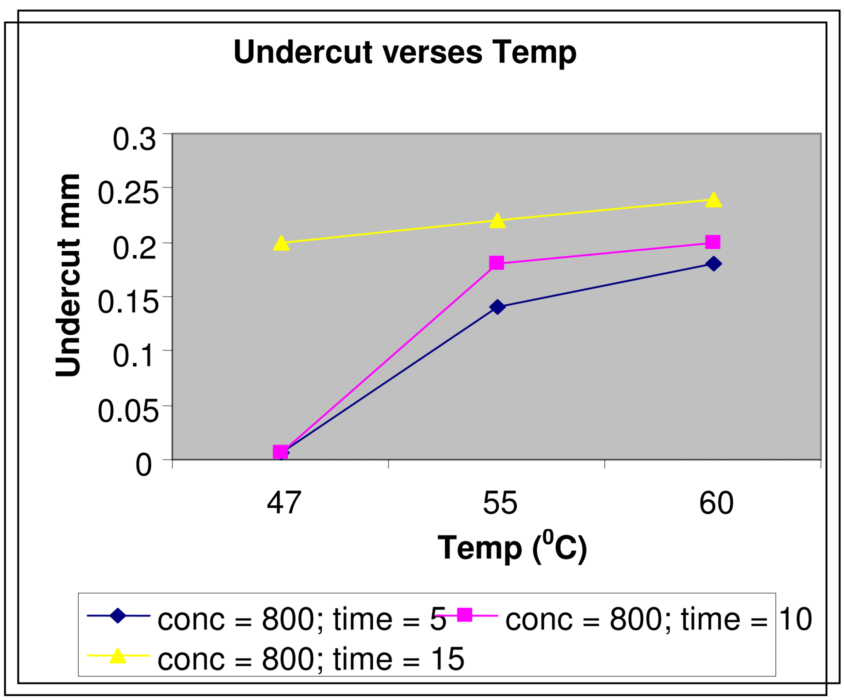


**Fig. 4** Graph of Undercut verses Temp

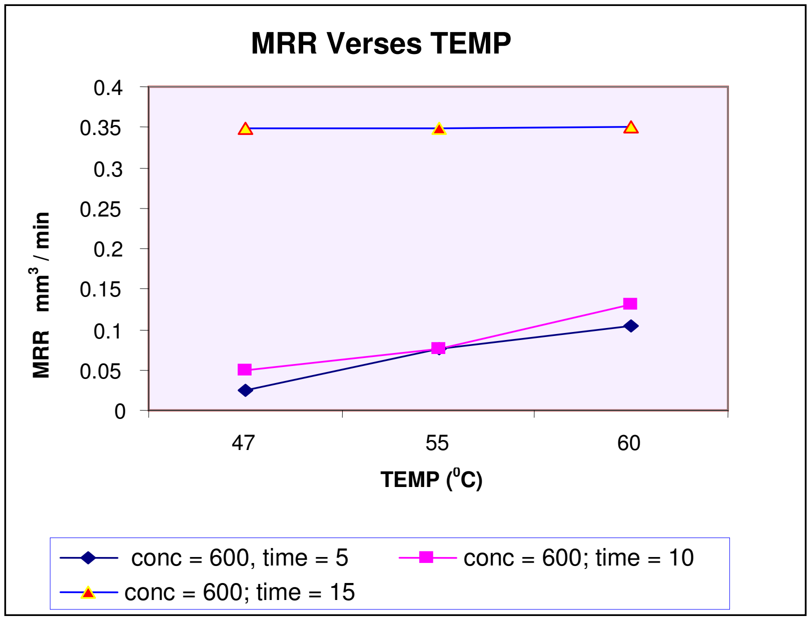


**Fig. 5** Graph of MRR verses Temp

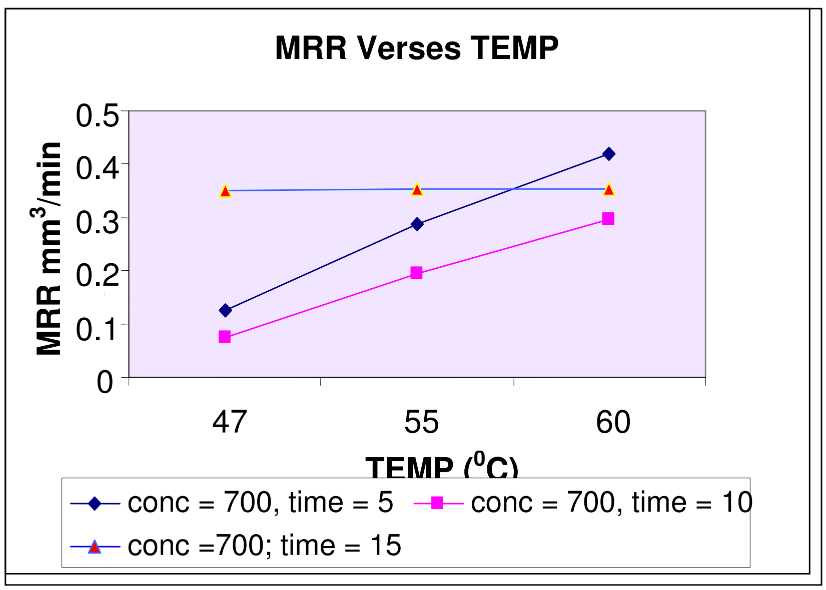


**Fig. 6** Graph of MRR verses Temp

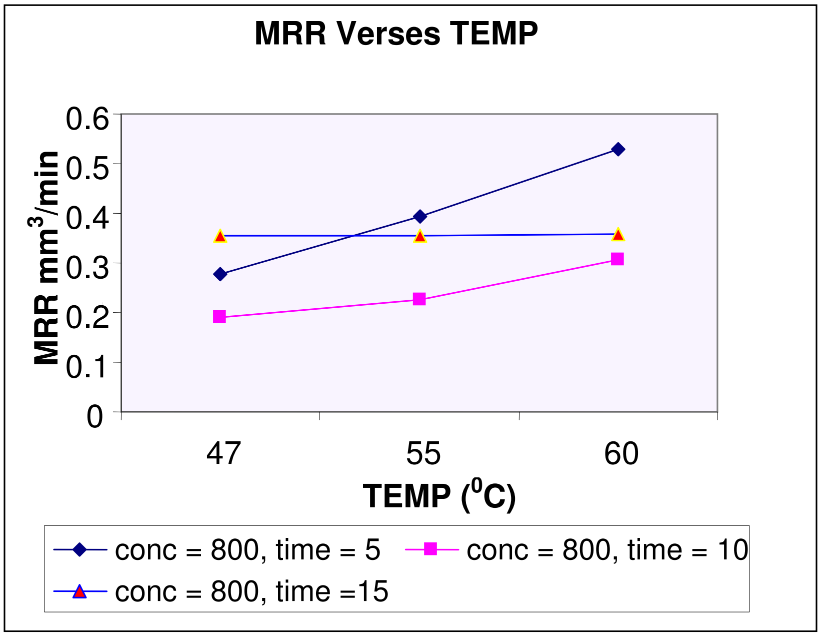


**Fig. 7** Graph of MRR verses Temp

**Table 1** Control parameters

| Factor / parameter | Level l | Level 2 | Level 3 |
|---|---|---|---|
| **Temp. (°C)** | 47 | 55 | 60 |
| **Conc. Of etchant (gm/lit.)** | 600 | 700 | 800 |
| **Time (Min.)** | 5 | 10 | 15 |

**Table 2 Fixed parameters**

| Sr. No. | Parameters | Particular |
|---|---|---|
| 1 | Etchant | Ferric Chioride |
| 2 | Work piece material | Copper Foil |
| 3 | Work piece thickness | 0.080 mm |
| 4 | Work piece volume | 32 $mm^3$ |
| 5 | Work piece size | Sq. 20 mm x 20 mm |

**Table 3 Design Matrix**

| Test | Temp. | Conc. | Time |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 |
| 4 | 1 | 2 | 2 |
| 5 | 1 | 2 | 2 |
| 6 | 1 | 2 | 2 |
| 7 | 1 | 3 | 3 |
| 8 | 1 | 3 | 3 |
| 9 | 1 | 3 | 3 |
| 10 | 2 | 1 | 2 |
| 11 | 2 | 1 | 2 |
| 12 | 2 | 1 | 2 |
| 13 | 2 | 2 | 3 |
| 14 | 2 | 2 | 3 |
| 15 | 2 | 2 | 3 |
| 16 | 2 | 3 | 1 |
| 17 | 2 | 3 | 1 |
| 18 | 2 | 3 | 1 |
| 19 | 3 | 1 | 3 |
| 20 | 3 | 1 | 3 |
| 21 | 3 | 1 | 3 |
| 22 | 3 | 2 | 1 |
| 23 | 3 | 2 | 1 |
| 24 | 3 | 2 | 1 |
| 25 | 3 | 3 | 2 |
| 26 | 3 | 3 | 2 |
| 27 | 3 | 3 | 2 |

**Table 4** Analysis for total average undercut response

| Factor | Level 1 | Level 2 | Level 3 | Max.- Min. |
|---|---|---|---|---|
| Temp. ($^{o}$c) | 0.0560 | 0.1255 | 0.1688 | 0.1128 |
| Conc. (gm/lit.) | 0.0748 | 0.1023 | 0.1520 | 0.0772 |
| Time (min.) | 0.0760 | 0.0930 | 0.1800 | 0.1040 |
| Mean value for the undercut = 0.1142 | | | | |

**Table 5** ANOVA summary table for Undercut in (mm).

| **Factors** | **D.F.** | **S.S.** | **M.S.** | **F** | **F $_{critical\ at}$ α=0.05** | ***p*- value** | **Significant (Yes / No)** |
|---|---|---|---|---|---|---|---|
| Temp. ($^0$C) | 2 | 0.058379 | 0.29189 | 21.20 | 3.49 | 0.000 | Yes |
| Conc. (gm / lit) | 2 | 0.27602 | 0.013801 | 10.03 | 3.49 | 0.001 | Yes |
| Time (Sec.) | 2 | 0.55017 | 0.27509 | 19.98 | 3.49 | 0.000 | Yes |
| Error | 20 | 0.027532 | 0.001377 | | | | |
| Total | 26 | 0.168530 | | | | | |

**Table 6** Analysis for total average material removal rate response

| Factor | Level 1 | Level 2 | Level 3 | Max.- Min. |
|---|---|---|---|---|
| Temp. ($^o$c) | 0.1998 | 0.2569 | 0.3335 | 0.1337 |
| Conc. (gm/lit.) | 0.1679 | 0.2732 | 0.3492 | 0.1813 |
| Time (min.) | 0.2488 | 0.1890 | 0.3524 | 0.1634 |
| Mean value for the MRR = 0.2634 | | | | |

**Table 7** ANOVA summary table for material removal rate

| **Factors** | **D.F.** | **S.S.** | **M.S.** | **F** | **F $_{critical\ at}$ α=0.05** | ***p*- value** | **Significant (Yes / No)** |
|---|---|---|---|---|---|---|---|
| Temp. ($^0$C) | 2 | 0.080977 | 0.040488 | 5.37 | 3.49 | 0.014 | Yes |
| Conc. (gm / lit) | 2 | 0.149159 | 0.074580 | 9.89 | 3.49 | 0.001 | Yes |
| Time (Sec.) | 2 | 0.122913 | 0.061456 | 8.15 | 3.49 | 0.003 | Yes |
| Error | 20 | 0.150845 | 0.007542 | | | | |
| Total | 26 | 0.503893 | | | | | |