Optimization of Process Parameter on Photo-Chemical Machining of 316L using RSM Method

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Abstract: **This paper focused on optimization of process parameters of using SS 316L material. Optimization is the process of getting best results by process and controlling parameters. Also study use of different parameters like time, temperature and concentration. The one of important objective is that getting best result using method and material (SS 316L), and use this optimum result for developing application for water, blood testing kit, and mixing of two fluids. The effect of process parameter is carried out using RSM method. Similarly the machining is carried using $FeCl_3$ as etchant and SS 316L as material on which we get best results.**

***Keywords*:**
PCM: Photochemical Machining
UV: Ultra Violet Exposure
$FeCl_3$: Ferric Chloride
RSM: Response Surface Machining
MRR: Material Removal Rate

1. Introduction

Photochemical machining one of method process of chemical milling for manufacturing microfluidic channels, for different testing purpose. PCM is a materials removal process that offers UV light and chemicals like $FeCl_3$ as machine tools. With this procedure, micron photographs and photoresists are carried for removing material cut. PCM offers more difficult designs and definition are feasible, close tolerance parts can be machined under controlled conditions.

PCM gives best result including MRR, undercut, depth of cut, surface roughness etc. for optimization using PCM we require knowledge of above parameters. In optimization there are two parameters process parameters and controlling parameters. There is much more research done on PCM using different materials and methods. RSM is one of selected method plots graph on basics of time, temperature and $FeCl_3$ concentration.

Here the optimization of process parameter take place by adjusting process parameters like time, temperature and concentration. Selection of material as SS 316L gives more important parameters as low carbon percentage, it is bio-compactible material and good corrosion resistance property.

PCM carried out in selected areas of testing different material properties to give optimum results. It is much complicated process for highly complex parts with higher accuracy. Also machining of polished metal pates etching done with less accuracy. Cost carried for PCM apparatus is higher for initial investment and proper maintenance of all electrical instruments as heater in etching tank, UV exposure photoresist tank, along with protect from dust gives good result. For getting accuracy of work in few micron of available thickness.

Similarly if microfluidic channels occur on work the different parameter testing is done on work piece.

1.1 Objectives of Dissertation:

- To find out suitable conditions for best machining.
- Study Photochemical Machining Process.
- Designing of various photo tools with selective geometry of shape.
- Analyze of amount of time required for process.
- To manufacture micro level product.
- To measure parameters MRR, Depth of cut, Etch factor etc.
- Set up design and testing and maintenance.
- Analysis of optimum values.
- To obtained high accuracy micro channel on SS 316L by photochemical machining process.
- Implementation of the Photochemical Machining Process to form the micro channel on SS 316L steel.
- The main objective is that test various fluids like water, blood, petrol, and diesel etc. and obtain their properties.

2. Experimental Setup

PCM is the process of machining is a very cheap process, the main initial cost of the experimental setup as equipment used for the PCM process are much more very expensive. But along the machining is cheaper due to the use of the cheaper chemicals. So therefor we have prepared an optimization using experimental setup for the process it consists of the following five units:

2.1 Air Dryer:

Fig Shows (1) the air dryer is a mica coiled heater engulfed in a U- shaped hollow copper tube placed in a metal sheet box. The heater is run on 2 amp AC supply. The heater is well insulated and protected to prevent any chances of electric shock to the user and properly grounded. The Dryer unit has a hinged wooden lid and metal hooks are provided below the lid to suspend the specimens from the hooks.

2.2 Dip Coater:

Fig Shows (2) a rectangular shaped tank is provided for photoresist coating which is attached to main machine. Tank capacity is five liters approximately. The combined unit is for curing of liquid photoresist. Electronic timer (4-5 min), controlled heating system allow fast and efficient drying. The apparatus is manufactured by steel material. Heating finned heaters with thermostat controls and air circulation. Maximum component size is 260×310 mm. The Dip coater consists of a small container made of sheet metal which is used to store the highly photosensitive. The photoresist solution being very thick and viscous in nature. Dip Coater so that while dipping out the specimen into the photo-resist it does not touch the walls of the container and hence ensure proper application of the photo-resist onto the specimen. Care should be taken while dip coating specimen for get almost best accuracy of work.

2.3 UV Exposer:

Fig Shows (3) UV Exposure is made up of MS sheet with coated surface. Maximum component size 260×310 mm. The UV exposer is a unit which opens into two from the center. It contains 3 UV tubes. The lower half contains 3 UV tubes of 260mm size and 8W rating and the DC adapters under these tubes which is used to run the tubes. These UV tubes are placed at a distance of 55mm from a 3mm thick glass sheet over which specimen is to be placed which means that the specimen are placed which means that the specimen are placed at a distance of 55mm from the UV source.

The UV rays being harmful to naked eyes the unit is provided with a safety push to ON switch which will make sure that the UV tubes start only after the unit is properly closed. As soon as the operator opens the unit the UV tubes are turned OFF for the safety of the operator. The UV tubes run o DC power supply so we have used DC adapters which will convert the AC power into DC power.

2.4 Etching Tank:

Fig Shows (5) Etching tank is constructed using poly vinyl chloride with welded joints used for fast single and double sided etching. Corrosion free construction material used to protect from corrosion. This unit is the place where the real machining of the work piece takes place. The etchant solution ($FeCl_3$) has tendency to dissolve a big list of metals and alloys in it so the direct etching of the etching tank itself. So the etching tank was made of Polyurethane material which contains Titanium heater and a Thermostat.

For varying the temperature parameter among the input parameters a heater is employed which is kept dipped inside the etching solution. There is a possibility that the heater may get dissolved inside the solution. To prevent any chances of such accidents Titanium heater was used. Titanium the strategic metal being a highly stable does not get affected by the etchant solution and hence the heater coated stable does not get affected by the etchant solution and hence the heater coated with titanium is used of 1200℃. The heater works on 230V AC power supply.

To maintain the required temperatures a thermostat coupled to a thermocouple is used which is kept dipped inside the solution. The thermocouple being an active transducer it does not require an external power supply to run the thermostat. The thermostat heater is connected in series to power supply unit and heater. The 40℃ to 100℃ can be set so that the heater will cut off in the specific range of temperature when the heater crosses the required temp and again start back when the temperature falls down from the required temperature. Keep the developed work piece in the net bag which is totally dipped in the etchant. Adjust the time and temperature as per experimental planning. Heating elements and cooling elements helps to keep constant temperature of etchant.

An indicators is connected in parallel to the heater so that it won't consume extra current meant for the heater and affect the working of heater. The indicator hence glows when the heater is running and when the indicator is not glowing it means that the heater is in cut off condition and not working. The whole set up is shown as in figure.1

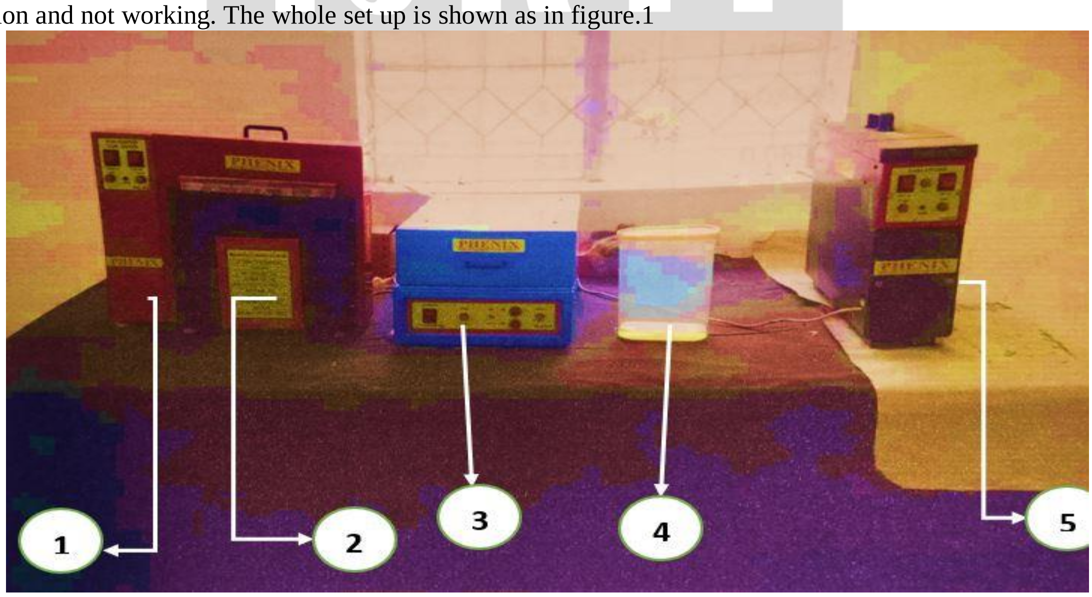


Fig.1 Experimental Setup

1. Air Drier
2. Photoresist tank for dip coating
3. UV Exposure kit
4. Developer tank
5. Etching Tank

3. Experimental Procedure

Photo chemical machining is a production techniques for the manufacture of burr free and stress free and flat metal components by chemical etching using photo tool. Photo chemical machining process is very economical and used for produce various process parameters shapes from different metals and alloys. During the process various process parameters like etch factor concentration, under cut, also consider surface roughness effect on material removal rate of the process. Following are steps in PCM process:

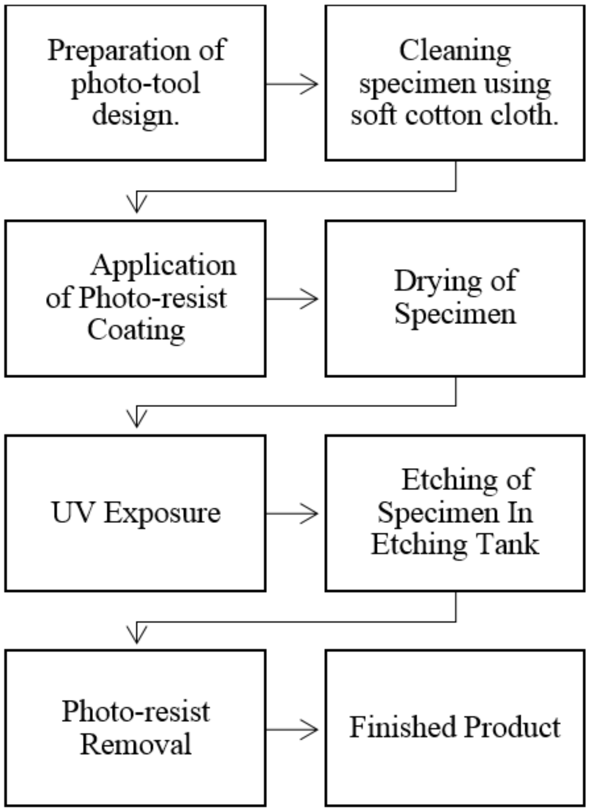


Fig.2 Flowchart describing PCM process

3.1 Photo-tool design Preparation:

The photo tool generation step is usually done in a Corel Draw Software. The artwork is to a laser imager that exposes the desired image on photographic film and then exposed film is then developed. This, film areas exposed by the laser imager become opaque to UV light whereas unexposed areas become transparent. Basically, a photo-tool is a clear polyester sheet with black lines and therefore contains the Master Image Pattern. This photo-tool allows transference of this image on the photo resist. In PCM, double sided photo-tool is usually manufactured as etching is usually carried out on both sides of the metal simultaneously in order to reduce undercutting phenomenon. Photo-tools allows fine details to be obtained and the shape of the part can be changed very easily. Thus, modifying in part deign is not a problem because photo-tools are relatively inexpensive.

3.2 Cleaning Specimen:

The process starts with cleaning the metal surfaces on which to having the photo-resist applied. The cleaning operation aims to remove any substance which is at the surface of the metal. Oil or grease would prevent good adhesion of the photo-resist on the metallic surfaces. Two main methods are used as first one is mechanical; it consists of scrubbing the metal sheet on soft cotton cloth and second one is chemical.

It can be noticed that a good solution for cleaning is efficient is to spray water. This phenomenon indicates an efficient cleaning. The cost of apparatus should be increased to improve PCMs techniques to machining different types of materials.

3.3 Photo-Resist Coating and drying:

Once the metal cleaning is done, the photo-resist can be applied to the dried metal. Photo-resists are liquid photopolymers which have their chemical structures altered by exposure to UV light. After dip coating the fine layer of photoresist occur on specimen. These specimen is dried in dryer with help of heater. The specimen is hanged in air dryer for 10 min or more for fine layer of photoresist.

3.4 UV Exposure:

Before being exposed to the UV light, the coating is with proper finish. During this process the photo coated work piece is placed on clean glass and start the UV exposure. This is fully automatic and safe step during matching. Wait for some time to expose the specimen. When UV exposure light is OFF the open the cover and do further process. This is much more important process because due to improper UV exposure causes whole process fails. Similarly proper care should be taken due to harmful UV light.

3.5 Etching of Specimen

In this process material is exposed to heated $FeCl_3$ during etching. It is the process which is time and temperature dependent process. During process $FeCl_3$ reacts with metal plate specimen and form chemical reaction with product along removes weak material section. Etching can be done due to dipping of specimen in chemical solution with heated $FeCl_3$. Etching machines is commonly used to withstand corrosion from etchant. Heater mostly used for heating chemical solution and compressor for stir the $FeCl_3$ and water mixture. These also help to maintaining constant temperature of etchant solution.

3.6 Washing along with Inspection

At the end of process there will be the photoresist still remain coated and hence removal of Photo-resist is very necessary for finalize the process. Photo-resist must be completely removed without from metal surface. After removing etchant measure thickness of etched work-piece which is to be inspected. The best method used for inspection is plug gauge and optical comparator. The PCM machined part inspected under microscope to checking under cut, MRR and surface roughness. After all depth of cut is measured using micrometer screw gauge and calculate MRR. Wash the components water under running water.

3.7 Shape of Work piece

For experiments purpose select circle shapes to get easy cross-sectional area and accurate dimensions.

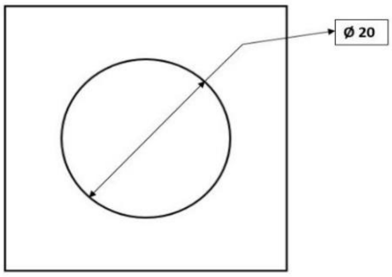


Fig.3 Shape of work piece

3.8 Requirement for Experimentation

- Material :316L SS
- Chemicals : $FeCl_3$
- Electrical Supply : 15V DC
- Digital weight meter, Micrometer screw gauge
- Thermometer, Stopwatch
- Liquid photo resist, photo resist thinner, photo resist developer
- Photoresist Dryer with heater
- Both side UV Exposure
- Etching Machine with heater and air compressor

4. Consideration of Etching Parameters

4.1 Control Parameters

- Temperature
- Time
- Etchant Concentration

4.2 Fixed Parameters

These are the parameters are depending on method and material have effect on measures the performance. In order to minimize their effect these parameter consider as constant. The Fixed parameter are as follow

- Etchant –Ferric Chloride
- Work piece Material - SS 316L Plate
- Work piece thickness - 0.8mm
- Work piece size- 50×30mm
- Work piece area -1500 mm^2

5. Design of Experimentation (L9 Array)

The main experimentation, were carried so as to ensure proper working of each instrument, levels of each process parameter were decided due in which are shown in Table 1

Table 1: Process Parameters

Sr. No.	***Process parameter***	***Levels***		
		1	***2***	***3***
1	Concentration of $FeCl_3$ (gm/lit.)	750	650	550
2	Temperature(°C)	60	50	40
3	Time(min.)	5	10	15

Level 1 High Level 2 Medium Level 3 Low

From the assigned levels of process parameters, experiments were studied using Design of Experiments RSM method and measurements of response variables were recorded for each set of experiment number from L9 array presented in table 2

Table 2. Experimental analysis

Expt. No.	*Process Parameter*			*Response Variables*			
	Temp. (℃)	*Time (min)*	*Conc. of $FeCl_3$ (gm/lit)*	*MRR (mm^3/min)*	*Undercut (mm)*	*Depth of Etch (mm)*	*Etch Factor*
A	60	5	750	0.00080	0.1508	0.004	0.0265
B	50	10	750	0.00150	0.0664	0.015	0.2259
C	40	15	750	0.00140	0.0254	0.021	0.8267
D	60	5	650	0.00040	0.1533	0.002	0.0130
E	50	10	650	0.00120	0.0283	0.012	0.4240
F	40	15	650	0.00113	0.0190	0.017	0.8947
G	60	5	550	0.00020	0.0399	0.001	0.2506
H	50	10	550	0.00050	0.0298	0.005	0.1677
I	40	15	550	0.00093	0.0150	0.014	0.9333

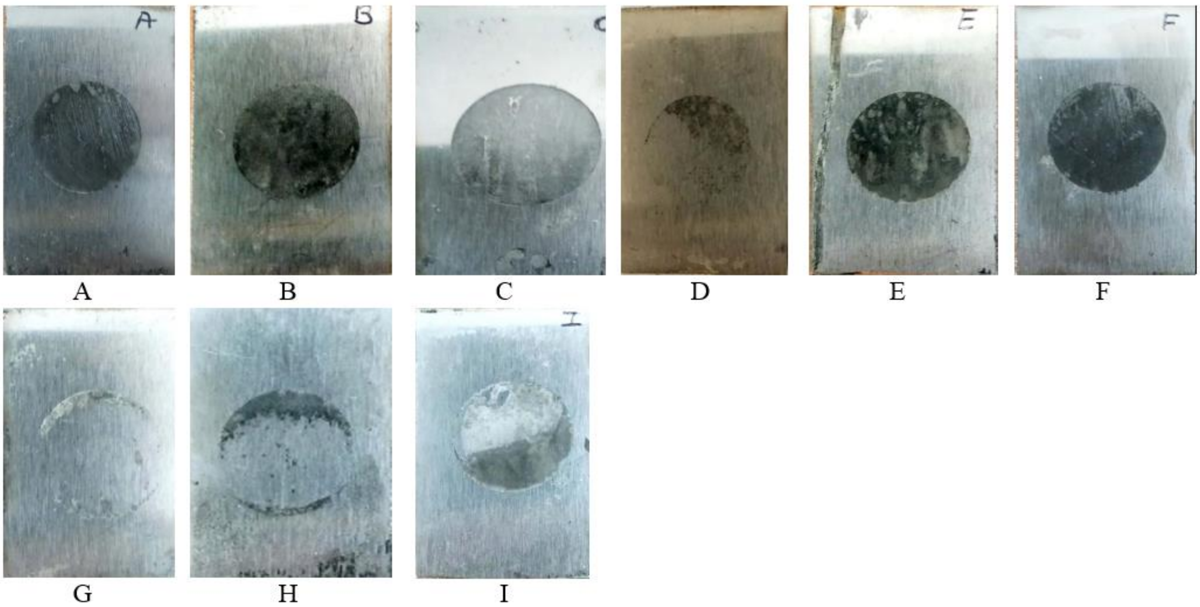
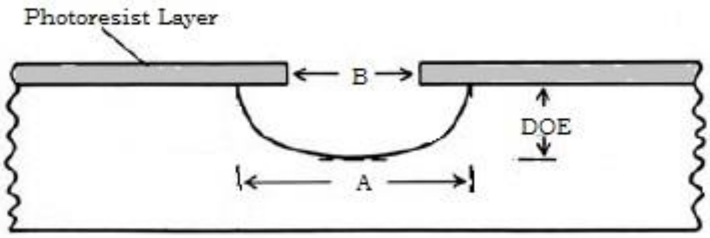


Fig.4 Tested Specimen by PCM Process

Etch Factor:

The process of etching doesn't give perfect cut there is always slightly undercut of material take place. Hence etching is always in undercut. It is defined as ratio of amount of depth of etch to undercut of material. Formula for Etch Factor

$$Etch\ Factor = \frac{Depth\ of\ Etch}{Undercut\ of\ Material}$$



Undercut of material:

It is defined as the amount of excess material removed during etching process.

$$\boldsymbol{Undercut = \frac{1}{2}(A - B)}$$

6. Response Surface Methodology (RSM)

Changes are made in the input variables in order to identify the changes in the output response. Originally, RSM was developed to model experimental responses into the modelling of numerical experiments. These can be represented graphically, in the form of three-dimensional space and contour plots are help analyze the shape. Contours curves along response drawn with plane keeping all variables should be fixed. Each plots gives particular height gives optimum result. With RSM technique, the effect of factors on quality criteria can be analyzed and optimum values has been obtained. In RSM design there should be at least three levels for each factor. The design expert (DE 10) software is used for developing the experiment results by RSM.

7. Statistical Analysis

Along with number of trials are required to analyze the results, the actual and the predicted undercut during process of material SS 316L are shown in graph. 5, Actual values and the predicted values are measured from the RSM design. The difference between the actual and predicted values shown in Table 3. It is clear of analysis is provided for selecting values from the experimental values.

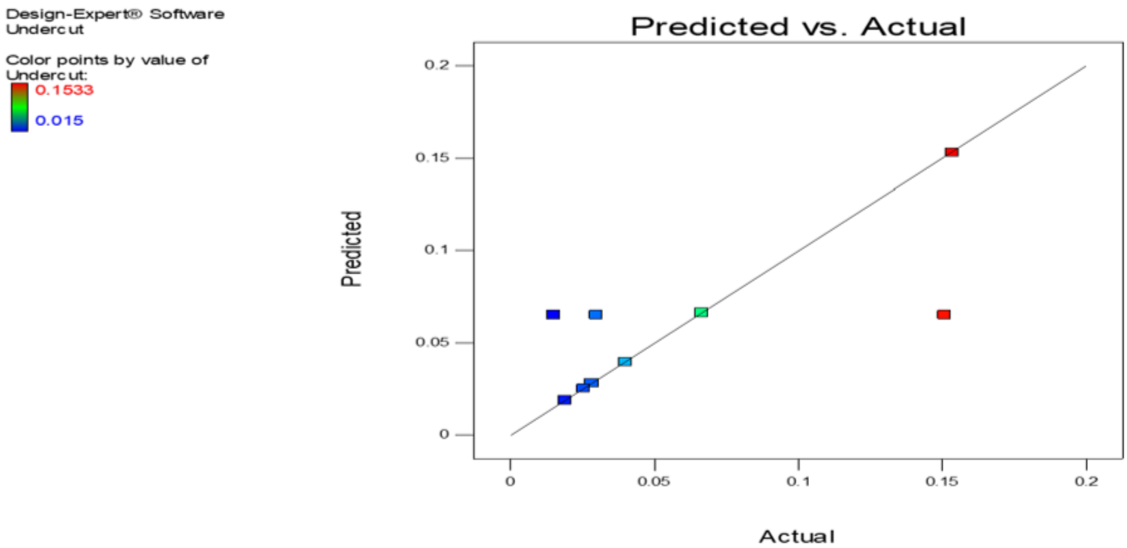


Fig.5 The actual and predicted graph of SS316L for Undercut parameter

Table 3. The difference between the actual and predicted values

Expt. No.	*Process Parameter*			*Response Undercut (mm)*		
	Temp. (℃)	*Time (min)*	*Conc. Of $FeCl_3$ (gm/lit)*	*Actual Values*	*Predicted values*	*Residual*
1	60	5	750	0.1508	0.0652	0.0856
2	50	10	750	0.0664	0.0664	0
3	40	15	750	0.0254	0.0254	0
4	60	5	650	0.1533	0.1533	0
5	50	10	650	0.0283	0.0283	0
6	40	15	650	0.019	0.019	0
7	60	5	550	0.0399	0.0399	0
8	50	10	550	0.0298	0.0652	-0.0354
9	40	15	550	0.0150	0.0652	-0.0502

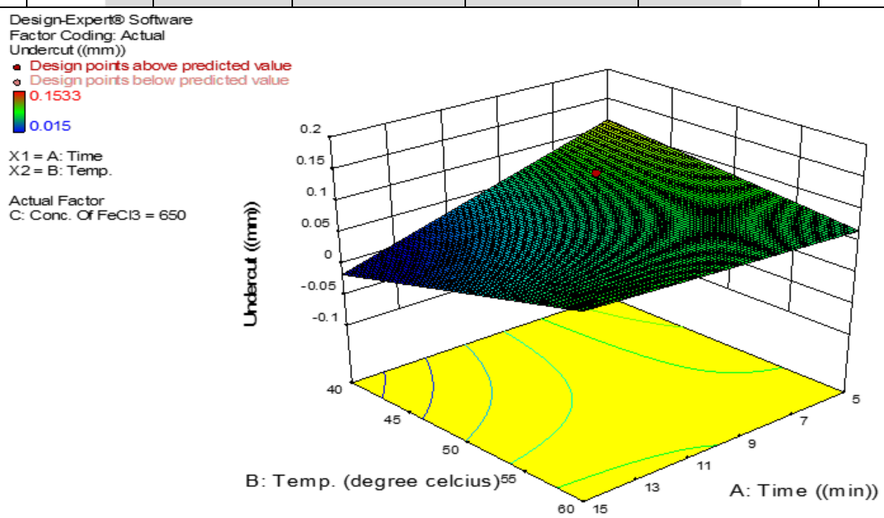


Fig.6 3D Surface plot of Undercut vs. Time, Temp

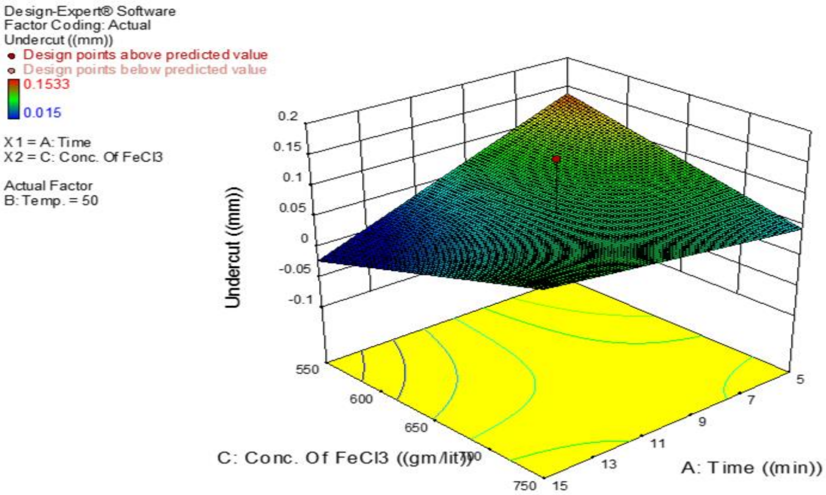


Fig.7 3D Surface plot of Undercut vs. Time, Temp

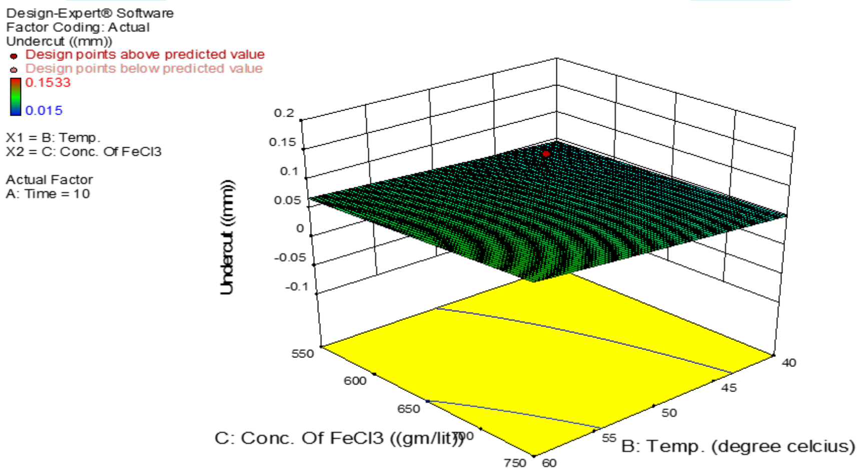


Fig.8 3D Surface plot of Undercut vs. Temp, concentration

8. Optimization by Response Surface Modelling

The main purpose of this project is to find the optimum value by different process parameters to develop application by PCM process using SS 316L material by using developed mathematical model equations. For optimization Design Expert v10 is used. The optimum conditions are determined for PCM process on SS 316L materials shown in Table 4.

Table 4 Optimization Result of PCM of SS 316L

Desirability	***Temp. (°C)***	***Time (min)***	***Conc. (gm/lit)***	***Undercut(mm)***
1.000	51.089	14.387	726.429	0.087

9. Etching Defects:

During photochemical machining different defects occur due to selection parameter of time temperature and concentration. At time of 5 min time the etching of complete circular specimen doesn't take place due to less time. Similarly at 15 min time full circular etching take place nut small defects occur as mouse bite defects.

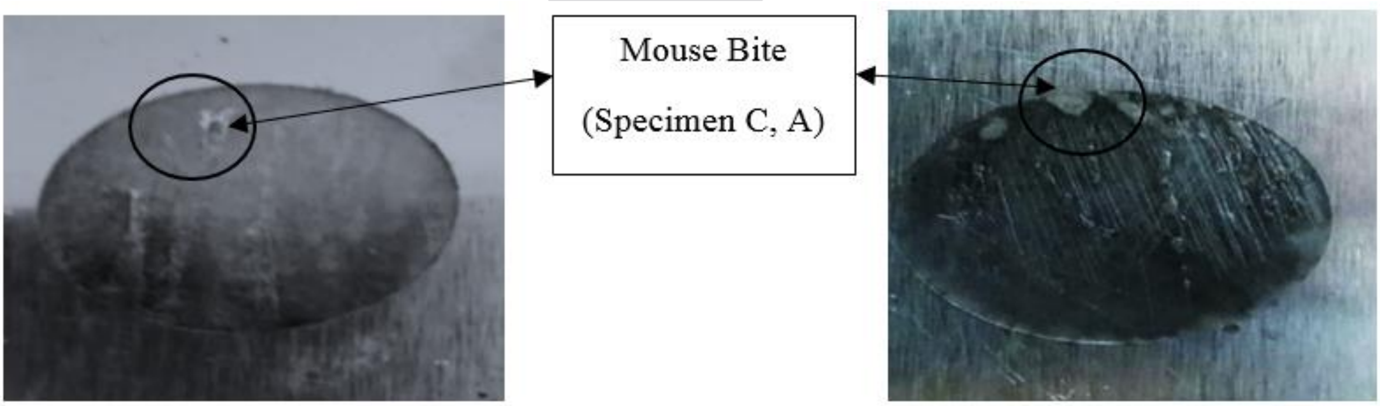


Fig.9 Etching Defects

Conclusion

Here conclusion obtained from results of optimization is that PCM of SS 316L done using L9 array design using etchant as ferric chloride ($FeCl_3$) and analysis carried out using RSM Method. Time, temperature and etchant concentration taken as controlling parameters. The main conclusion analyzed as follow:

- As the concentration increases the material removal rate also increases along with time and temperature.
- Along with increase in time also increases the depth of cut as much time getting to doing chemical process between metal and etching solution.
- There will be more attention is provided for controlling concentration of $FeCl_3$ with water ratio.
- This analysis shows that increase in time undercut increases ranges from 5-15 min.
- The optimal values obtained at Undercut 0.087 mm of SS 316L at optimum level of concentration, temperature and etching time and these were found to be 726.429gm/lit, 51.089^{0}C and 14.387min respectively.

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