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A Review of Issues in Photochemical Machining

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Abstract: *This paper presents the issues in machining of copper using Photochemical Machining (PCM). Twenty-seven experimental runs base on full factorial (3^3) Design of Experiments (DoE) technique can perform. The control parameters can consider the etchant concentration, etching temperature and etching time. The response parameters were Undercut (Uc) and the Surface roughness (Ra). The effects of control parameters on undercut and surface roughness can analyze using Analysis of Variance (ANOVA) technique and their optimal conditions can evaluate. An optimum surface roughness can observe at particular etching temperature, an etching concentration and etchings time. The minimum undercut (Uc) can observe at the particular etching temperature, etching concentration and etching time.*

Keywords: *PCM, DoE , ANOVA, Surface Roughness, Undercut.*

I. Introduction

The photo chemical machining process goes by many names, including photo chemical machining, photo chemical etching, chemical milling, chemical etching, photo etching, even the abbreviation "PCM." All of these names describe the same process. The photo chemical machining process is a means of fabricating thin gauge metal parts. The metal thickness rages from .001" to .080" depending on the type of metal. In the photo chemical machining process a stencil, called a "photo tool," is used to expose multiple images of the parts to be made on both sides of a sheet of raw material that has been coated with a light sensitive and acid resistant material, called "resist." After the images of the parts have been developed, and the uncured "resist" is washed away, the metal around the part is dissolved using an etching chemistry. The PCM is one of the non-conventional machining processes that produces a burr free and stress free flat complex metal components. The machining takes place using a controlled dissolution of work-piece material by contact of the strong chemical solution. The PCM industry currently plays a vital role in the production of a variety of precision parts viz. micro fluidic channels, silicon integrated circuits, copper printed circuit boards and decorative items. It is mainly used for manufacturing of micro-components in various fields such as electronics, aerospace and medical. It employs chemical etching through a photo-resist stencil as a method of material removal over selected areas. This technique is relatively modern and became established as a manufacturing process. The newly-developed products made from PCM especially relevant to Micro engineering, Micro-fluidics and Microsystems Technology. Copper is an important material for various engineering applications, as because of its excellent electrical and thermal conductivity, easy fabrication, and good strength and fatigue properties. An aqueous solution of ferric chloride ($FeCl3$) is the most commonly used etchant.

II. Background

Although the first photo resist was developed in 1826, the start of the photochemical machining industry seemed to coincide with the development of the highly successful KPR family of photo resists marketed by Kodak in the mid- 1950s. These photo resists were propensities and therefore easy to use.

The first PCM companies were formed in North America and the UK but soon the technology was also being applied in mainland Europe and the Far East. Later, the technology spread to Central and South America, Australasia, Central Asia and Southern Africa. The European countries behind the Iron Curtain were active in using PCM as part of their defense industry but, since the fall of the Berlin Wall in 1989, their PCM industry has been greatly contracted, especially in Russia and Bulgaria.

Many of the job-shop (sub-contract) PCM companies were started by entrepreneurs as small spin-off companies intent on manufacturing piece-parts as a rapid and economic alternative to stamping. Some larger companies believed that the PCM process was so critical to their production that it was brought in-house to gain competitive advantage and preserve confidentiality.

In the early days of commercial PCM, process technology was guarded jealously to the point that PCM was regarded as 'Manufacturing's Best Kept Secret'. However, the formation in 1967 of a small, USA-based trade organization, the Chemi Photocl Machining Institute (PCMI), did provide a focus for industrial PCM companies and that has eventually led to more open discussion of PCM technology and challenges. This organization now has international membership with regional Chapters in the USA and Europe. The Japanese Photo Fabrication Association (JPFA), formed in the late 1970s, provided a similar focus for Japanese PCM companies.

Many PCM companies have also expanded their process capability within the past ten years by installing additional laser cutting, wire-EDM, CNC routing, water jet cutting, forming, electroplating and/or photo electroforming (PEF) processes to form ‘one-stop shops’. The business philosophy is to utilize the best technique for both technical and financial benefit.

Research into PCM, outside company laboratories, has been concentrated since the mid-1970s into just a few universities and research institutes based in Europe (e.g. UK, Germany and The Netherlands), Japan and, more recently, China. Since 2000, with the cessation of PCM university research in mainland Europe and to further global pre-competitive research, Canfield University has set up five PCM Research Consortia each of one year’s duration.

The Consortia comprise over a dozen rival commercial PCM companies from across the world with the common objective of investigating current industrial PCM challenges. The formation of the consortia constituted the first occasion of PCM multi-collaboration across company and country boundaries.

III. Steps Involved In PCM Process

3.1. Preparation of masters/photo tool

It serves as tool in PCM. It begins with generation of oversize art-work or paper. Art-work is usually generated at some magnification factor to minimize dimensional error. Art-work can be generated by manual drafting or by precision coordination graph plotting or by computer aided drafting. The art-work is photographed with precision reduction camera. In high volume production of parts, multiple image masters are used to expose, develop, etch a number of parts. It results in master film that contains the pattern to be etched. Sets of films are made to facilitate simultaneous exposure from both sides. During master’s preparation, provisions are made for reclaiming of parts after etching.

3.2 Selection of metal

Metals should have grain size as fine as possible, because the smoothness of edges of the parts decreases with increase in grain size. A metal that is soluble in etchant should be chosen. A material should be flat and of uniform thickness. Surface finish should be uniform and it should be free from scratches, embedded particles or inclusions.

3.3 Preparation of work piece

To have good adhesion between metal and photo resist metal surface must be free of contaminants. Work piece should be cleared by spraying water on metal surface and determining whether the individual droplet spread out to form thin film of water. Formation of film indicates adequate cleaning. The work piece is then rinsed and dried.

3.4 Masking with photo resists

Photo resists provides photosensitive surface that resists the action etchant. The photo resist can be either positive or negative masking. In positive acting system area that is exposed to light washes away during development. In negative system, exposed areas are made insoluble in the developing solutions. Photo resists can be applied by dipping, whirl coating, or spraying. The resists are dried at room temperature and then baked for 15 minutes at maximum temperature of 120 ºC. Exposure of photo resists to ultra-violet light polymerizes exposed areas of light sensitive resin, increasing resistance of these areas to chemicals used as developers.

3.5 Etching

The developed and post baked panel of metal is exposed to heated acid during etching. The acid reacts with exposed metal and oxidizes it to form soluble reaction product. Etching can be done either by immersion in agitated chemical bath or spraying with heated acid. When etching has proceeded to a point at which penetration from each surface has gone half way through the sheet, the break through occurs. Etching machines are made that can withstand corrosion from etchant. Machines have some at the base that contains the etchant. Heating element and cooling coil helps to maintain constant etchant temperature. An etcher with conveyor system allows continuous processing. In batch type machines one sheet at a time is processed.

3.6 Stripping and inspection

After etching, panels are still remain coated with photo resist, removal (stripping) of photo resist is necessary. Photo resist should be removed without staining the metal surface. Handling of parts during stripping is easier when the parts remain attached to metal sheet. Connecting tabs are located such that they do not interfere with function of part. Thickness of etched work piece is inspected. The best method of inspection involves plug gauges and horizontal optical comparator.

IV. Steps For Experiments Designing

4.1 Recognition of and statement of the problem

This may seem to be a rather obvious point, but in practice it is often not simple to realize that problem requiring experimentation exists, nor is it simple to develop a clear and generally accepted statement of this problem. It is necessary to develop all ideas about the objectives of the experiment.

4.2 Choice of factors, levels, and range

When considering the factors that may influence the performance of a process or system, the experimenter usually discovers that these factors can be classified as either potential design factors or nuisance factors. The potential design factors are those factors that the experimenter may wish to vary in the experiment. Some useful classifications are design factors, held-constant factors, and allowed-to-vary factors. Noise factors are often classified as controllable, uncontrollable, or noise factors. A controllable nuisance factor is one whose levels may be set by the experimenter. If a nuisance factor is uncontrollable in the experiment, but it can be measured, an analysis procedure called the analysis of covariance.

4.3 Selection of the response variable

In selecting the response variable, the experimenter should be certain that this variable really provides useful information about the process under study. Most often, the average or standard deviation (or both) of the measured characteristic will be the response variable. Multiple responses are not unusual.

4.4 Choice of experimental design

If the pre-experimental planning activities above are done correctly, this step is relatively easy. Choice of design involves the consideration of sample size (number of replicates), the selection of a suitable run order for the experimental trials, and the determination of whether or not blocking or other randomization restrictions are involved.

4.5 Performing the experiment

When running the experiment, it is vital to monitor the process carefully to ensure that everything is being done according to plan. Errors in experimental procedure at this stage will usually destroy experimental validity. Up-front planning is crucial to success. It is easy to underestimate the logistical and planning aspects of running a designed experiment in a complex manufacturing or research and development environment.

4.6 Statistical analysis of the data

Statistical methods should be used to analyze the data so that results and conclusions are objective rather than judgmental in nature. If the experiment has been designed correctly and if it has been performed according to the design, the statistical methods required are not elaborate.

4.7 Conclusions and recommendations

Once the data has been analyzed, the experiments must draw practical conclusions about the results and recommend a course of action. Graphical methods are often useful in this stage, particularly in presenting the results to others. Follow-up runs and confirmation testing should also be performed to validate the conclusions from the experiment.

V. Experimental Setup

During experimentation; temperature, the time of etching and concentration of etchant is necessarily to be changed. For this heating bath is used which varies temperature from 20° C to125°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 placing of etching machine as shown in Figures below.

Fig.5.1 PCM lab

Fig. 5.2 Work part preparation

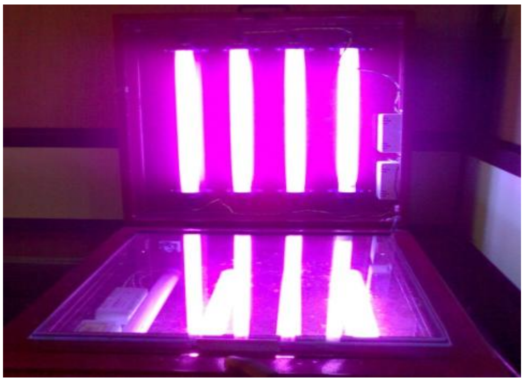

Fig. 5.3 U. V. Exposure

Fig. 5.4 Negative maker

Fig. 5.5 Photo resists coater

Fig. 5.6 Etching machine

VI. Selection Of Pcm Parameters

Many parameters affect the performance of PCM 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 may 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.

- **Control parameters:-** Temperature (^{0}c),Concentration(gm/lit),Time (min).
- **Fixed parameters:-** Etchant ,Work piece material, Work piece thickness,Workpiece area ,Work piece size.
- **Response variables**:-Surface roughness.

VII. Conclusion

Cakir (2006) studied that the copper etching with $CuCl_2$ etchant and a suitable regeneration process of waste etchant simultaneously. This would reduce the overall manufacturing cost and environmentally friendly etching process which ultimately enhances the productivity. David et al. (2004) studied the characterization of aqueous ferric chloride etchant used in industrial photochemical machining. He found that FeCl3 is most commonly used etchant with a wide variety of grades. Rajkumar et al. (2004) investigated the cost model for PCM which defines standards for industrial etchants and methods to analyze and monitor them. Cakir (2004) stated that the etch rate of $FeCl_3$ is higher than $CuCl_2$ but $CuCl_2$ gives a better surface finish than $FeCl_3$ during machining of Cu-ETP copper.

The main limitation of PCM is to be found in the characteristics of isotropic etching whereby the etchant will attack not only downwards in to the metal but also sideways beneath the resist stencil layer .The ratio of depth to the undercut is termed the “etch factor”. A relatively high level of operator skill is required**.** Special safety precautions are needed in handling of chemicals; the etchant vapors also very corrosive. Etching equipments must usually be isolated from other plant equipment Suitable photographic facilities are not always available Maximum metal thickness that can be blanked is about 1.6 mm Sharp radii cannot be produced.

It is observed that no statistical study has been reported to analyze the interaction effects of process parameters on etching process of Copper. Till date an accuracy of PCM depends only on the skill and experience of the operator. Work to date an optimal set of process parameters is not calculated. The statistical study is necessary to investigate the performance in different ranges as well as to find the global optimum process parameters. It is also necessary to find out the single optimum process parameters setting to satisfy the requirements of excellent etching quality. In this work, an attempt is made to study the optimum process parameters by using full factorial design method and an ANOVA technique.

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