Chapter – 6

CHEMICAL MACHINING (ChM)

6.1 INTRODUCTION

Chemical machining is one of the best non-conventional machining process for machining complex machine components, decorative parts, etc. for different applications. Presently chemical machining is also used to fabricate the micro features such as micro holes, micro slots, profiles, and micro structures of higher aspect ratio on micro components like MEMS and in semi-conductor industries. The chemical machining is also known as etching, chemical etching, wet etching, etc. Well developed and established, simple, absence of tool, and economical to implement are the important features of this process. Chemical machining employs controlled material dissolution from workpiece surface by chemical reaction with concentrated acidic or alkaline chemical reagent. Chemical resistive coating called mask, is applied to the worksurface area or the portion of workpiece from which material is not to be removed. During machining unmasked area of the worksurface gets exposed to the chemical reagent and gets oxidized. This process has important steps namely workpiece cleaning, coating or masking, scribing of the mask, etching, and demasking. Environmental impact must be considered while using this process, because most of the chemicals used in this process are hazardous. However, use of ecofriendly chemicals, and regeneration of the waste etchants makes chemical machining process more applicable for today's industries.

6.2 WORKING PRINCIPLE OF CHEMICAL MACHINING

Figure 6.1 shows the schematic for the working principle of chemical machining. Chemical machining employs controlled material dissolution from workpiece surface by chemical reaction with concentrated acidic or alkaline chemical reagent. Chemical resistive coating called as mask, is applied to the worksurface area or the portion of workpiece from which material is not to be removed. During machining, unmasked area of the worksurface gets exposed to the chemical reagent and gets dissolved due to oxidation. This process has important steps such as workpiece cleaning, masking, scribing of the mask, etching and de-masking.

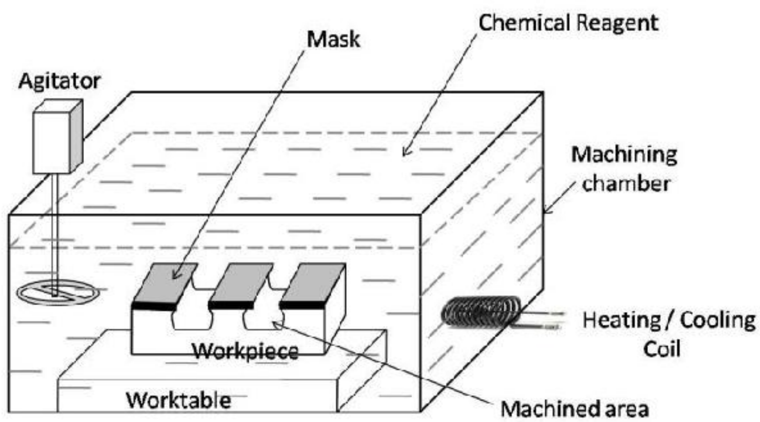

Figure 6.1 Schematic for working principle of chemical machining

6.3 MATERIAL REMOVAL MECHANISM IN CHM

Chemical machining process involves various steps in machining the raw workpiece to the finished or semifinished machine component. Figure 6.2 illustrates schematically the various steps of material removal in chemical machining, that are described as below:

6.3.1 Cleaning the workpiece

The workpiece material must be clean at the start of machining process for uniform removal of material. The purpose of the cleaning the workpiece before machining is to ensure the removal of an oil, grease, dust, rust, paint, ink, oxides etc. from the worksurface. Workpiece cleaning involves (i) applying solvent or vapour degreaser to remove oil, primer, ink etc. (ii) dipping in alkaline to remove dust oil stains, primer, ink, etc. (iii) dipping in deoxidizer to remove the oxide or the scaling, (iv) rinsing after every step to avoid mixing of ensure cleaning agents, and (v) drying the workpiece finally. Proper cleaning of the worksurface also enhances the effective adhesion of the mask material, and improves the machining accuracy. Mechanical cleaning method may damage the thin and delicate workpiece and hence, workpiece must be handled carefully during and after cleaning.

6.3.2 Masking the desired surface

A resistive coating known as maskant is applied to desired worksurface area or portions of the worksurface. The maskant are chemically resistant to the etchant i.e. chemical reagent. Hence, the maskant are applied on the portion of the workpiece surface, from which material is not to be removed. The masking material should be easily strippable, chemically secure and adherent to worksurface, enough to stand chemical abrasion during etching. Shape and size of the workpiece, number of parts to be machined, and complexity of the geometry are the important parameters that must be considered before selecting the mask. Workpiece can be masked by dipping, flow coating or spraying techniques.

6.3.3 Scribing

The work surface areas or the portion of the workpiece from which the material has to be removed are exposed by scribing the applied mask. For scribing the mask, thin bladed knife are generally used, however mask can also be pilled off by hand also. Pre-shaped mask templates can also be used to machine the complex shapes. While deciding the area of scribing, allowance for the undercut must be considered.

6.3.4 Etching

Etching is nothing but an accelerated and controlled corrosion of the workpiece material by suitable chemical reagent. This is the step in which material is selectively removed from workpiece surface. The masked component is immersed in chemical reagent, in which un-masked surface areas are exposed to etchant that attacks the workpiece material. Etching process gives better performance at higher etchant temperatures, and the temperature range depends upon the workpiece material, solution type, its concentration and etching period. Finally, the etched workpiece is rinsed out to clean the etchant from machined surface.
Overall etching, selective etching, multi-step etching, chemical blanking and taper etching are the various types of etching by which material can be removed from the workpiece. In overall etching workpiece is cleaned and mask is not applied on any of its surface, hence material removal takes place from all the sides of the workpiece. The purposes of overall etching are to reduce weight of forged components, castings etc., to manufacture metallic sheets of non-standard thickness, to remove oxide layer from the part surfaces, and to modify the surface properties. In selective etching, maskant is applied on the workpiece surface and scribed the desired outline. In multi-step etching, surfaces or features having varied etching depths can be manufactured. In chemical blanking, selective etching is performed simultaneously from both the sides to manufacture through features. Taper etching is used manufacture the tapered features, in which workpiece is initially immersed in etchant and then withdrawn out at controlled rate.

Ferric chloride ($FeCl_3$), hydrochloric acid (HCl) or their combination are the commonly used etchant in chemical machining of iron-based alloys, copper and its alloys, aluminium and its alloys. Cupric chloride ($CuCl_2$) is also used for machining of copper and its alloys in electronics industry, since it is easy to regenerate it by different regeneration methods.

The basic chemistry for etching metals with a solution containing $FeCl_3$ and HCl can be given as

$$xFe3^{+} + M \Rightarrow xFe_2^{+} + M^{x+}$$

where M is the etched material such as Fe, Ni, Cu, Cr, and ‘x’ is the valency of the etched metal,

$$FeCl_3 \Rightarrow Fe^{3+} + 3Cl^{-}$$

$$H_2O \Rightarrow H^{+} + OH^{-}$$

$$Fe^{3+} + 3OH^{-} \Rightarrow Fe(OH)_3$$

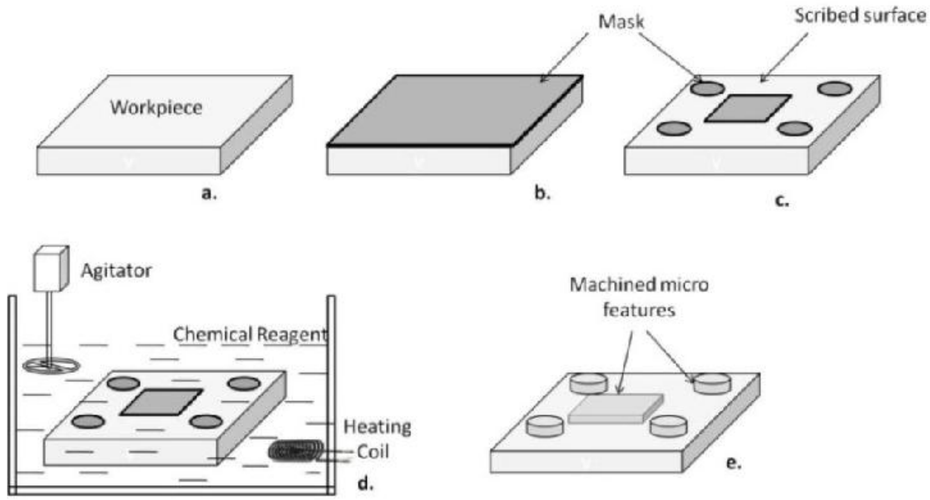

Figure 6.2 Schematics for steps in chemical machining a. cleaning, b. masking, c. scribed mask d. etching, and e. demasking

$$H^{+}+Cl^{-}\Rightarrow HCl$$

Regeneration reaction with Cl^{-} ions present in the solution

$$FeCl_2 + Cl^{-} \Leftrightarrow FeCl_3 + e^{-}$$

where e^{-} is an electron.

HCl itself can attack the substrate to form $FeCl_2$, the reaction with hydrochloric acid can be given as

$$Fe + 2HCl \Leftrightarrow FeCl_2+H_2$$

6.3.5 Demasking

This is the final step in this process. The masking material is removed from etched workpiece and cleaned for the removal for maskant as well etchants if any. Finally, the dimensional accuracy, and surface quality are verified before final dispatch of the finished part.

In chemical machining, material removal takes by etchant attack at the unmasked portion of the work material which penetrates into the worksurface with respect to time. Hence, material removal rate in CHM are designated as penetration rates, and given as mm/min. Workpiece surface area do not have any effect on the penetration rate. Various applications of CHM generally demand material removal in the range of less than few millimeters. During etching process, when the material removal takes place from the un-masked portion of the workpiece, some part of the material is also removed by the etchant under the sideways of the mask as shown in figure 6.3. This unwanted removal of the workpiece material below the sideways of the mask is called as ‘undercut’. This effect of undercut affects the machining accuracy, hence it must be considered while designing the mask to have machined features of specified shape and size i.e. dimensions.

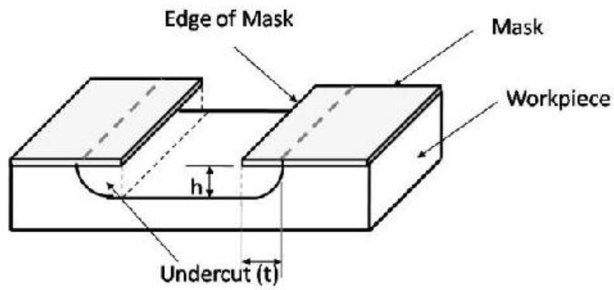

Figure 6.3 Undercut in chemical machining

In chemical machining, etch depth directly relates to the undercut, which can be given as

$$h \alpha u \quad (6.1)$$

this can be simplified as

$$h = Fe .u \quad (6.2)$$

where, 'u' is undercut (mm) for the etching depth of 'h' (mm), and 'Fe' is the etching factor.

Hence etching factor can be given as

$$Fe = h / u \quad (6.3)$$

i.e. Etching factor = Etching depth / Undercut

Different workpiece materials machined by chemical machining have different etching factors. For machining the accurate features of specific dimensions by chemical machining, etching factor is very much useful to find out the dimensions of the undercut below the mask. Etching factor of various materials are given in table 6.1.

Table 6.1 Etching factors of different work materials

Sr. No.	**Material**	**Etch factor**
1.	Mild steel	2.0
2.	Titanium and Titanium alloys	1.0
3.	Copper and Copper alloys	2.75
4.	Aluminium and Aluminium alloys	1.75

Etch rate is also an important parameter that must be considered in chemical machining. It is the rate at which material is removed per unit time. Etch rate plays significant role in deciding the total machining time for the specific product. During machining, if etching depth achieved is 'h', for the etching time 't', then the etch rate per side can be given as

$$E = h / t \quad (6.4)$$

where, h is etch depth (mm), t is the etching time (min), and E is the etch rate (mm/min).

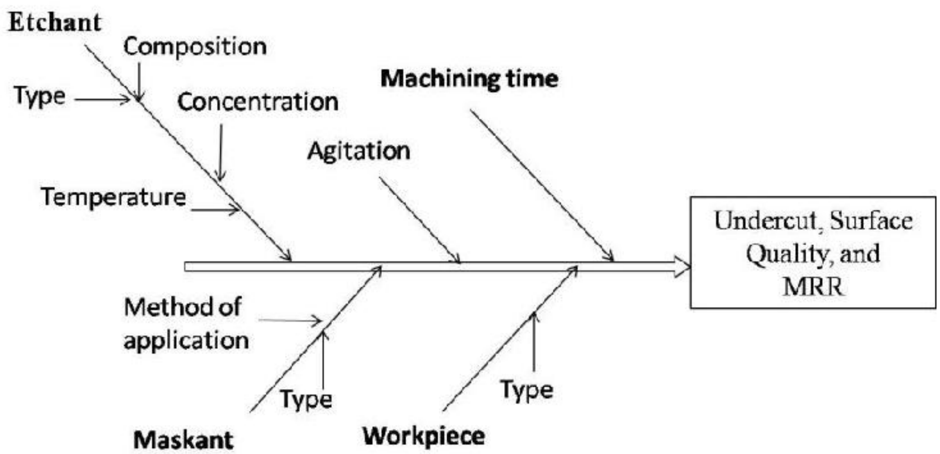

Figure 6.4 Fish-bone diagram for the chemical machining

are commercially available, whereas specific etchants for explicit requirements can also be prepared in laboratories or shop floors.

v. Maskant

The function of the masking material is to shield the workpiece material from chemical attack, to achieve the selective material removal. Generally polymer or rubber based materials used for masking procedure. Ideal mask material should be easy to apply and remove, non-reactive with etchant, easy to remove i.e. scribing, good adherence with workpiece surface, thermally stable, easily available and economical, etc. To enhance the etching resistance, multiple layers of maskant can also be used.

6.5 PROCESS PARAMETERS IN CHM

Figure 6.4 shows the fish-bone diagram or root-cause diagram of chemical machining. In chemical machining, etching accuracy i.e. amount of undercut, surface finish, and etching rate etc. are the important performance criteria, that are influenced by the various process parameters namely,

(i) Etchant related parameters like type of etchant, composition, concentration, and temperature of the etchant,
(ii) Maskant related parameters such as type of maskant, and method of application of maskant.
(iii) Type of workpiece material, and
(iv) Machining time, and agitation etc.

Etchant and maskant are the important process parameters in chemical machining process, which influences the performance of the process. Hence etchant and maskant related parameters have been discussed in brief.

Etchant

Important parameters that must be considered while selecting the etchant are workpiece material, etching depth, desired surface quality, possible damage to worksurface or change of metallurgical properties of work material, etching rate,

Figure 6.11 Components machined by photochemical machining optical encoder disc, fuel cell board, and precise machine part

6.8 ADVANTAGES AND LIMITATIONS OF CHM

Advantages

The chemical machining has various benefits over the other competing methods that are given as below:

(i) Chemical machining is the simplest method for reducing the weight of the workpiece.
(ii) Chemical machining is very much suitable to machine very thin sized workpiece i.e. thin sheets.
(iii) Mechanical properties of the workpiece such as hardness, ductility, etc. have no effect over the performance of the process.
(iv) Material can be removed from all sides of the complex shaped workpiece simultaneously.
(v) In chemical machining, no burrs are formed on the machined surface or features.
(vi) Chemical machining process generates worksurface without any residual stresses, and heat affected zone.
(vii) Very less initial cost is required.
(viii) Chemical machining process permits design changes very quickly.
(ix) Chemical machining requires less skilled workers.
(x) Chemical machining process does not require tools, that minimize the tooling cost.
(xi) Chemical machining results very good machining accuracy and good surface quality.
(xii) The work piece material does not involve any physical or chemical property changes.
(xiii) Scrap generation rate is very less in chemical machining.
(xiv) Chemical machining do not involve any mechanical forces, hence very sections such as honey comb can be easily manufactured.
(xv) Multiple workpiece can be machined simultaneously.

Limitations

However, chemical machining has some limitations also that can be given as:

(i) Chemical machining involves the handling of hazardous chemicals and harmful by-products.

(ii) In chemical machining, it is difficult to get the sharp corners along the edges of the machined features like hole, slot, groove etc.
(iii) It is very difficult to machine the workpiece of higher thickness.
(iv) Machining accuracy is limited by the scribing accuracy of the mask.
(v) Etchants used in chemical machining may be hazardous to the workers.
(vi) Etchants used in chemical machining may be hazardous to the environments also.
(vii) While designing the chemical machining setup, various subsystems must be made of corrosion resistance materials.
(viii) Chemical machining is very slow process because of it very low material removal rate. Low MRR may increase the operating cost of the process.
(ix) Environmental safety is the major issue in chemical machining, since it involves the handling and disposal of hazardous chemicals.

6.9 APPLICATIONS

Chemical machining can be easily applied to machine simple as well as complex features in very thin metallic sheets, which otherwise may not be possible by conventional techniques like stamping, punching etc. due to very thin sheet thickness. The common metals that can be processed by chemical machining include aluminum, copper, zinc, steel, lead, and nickel and their alloys which are very much suitable for majority of industrial products. Advanced engineering metals such as titanium, molybdenum, zirconium etc. as well as non-metallic materials like glass, ceramics, and some plastics can also be machined by this method. Chemical machining is not only suitable for machining the accurate features but also to enhance the surface quality of engineering products made of above materials.

Because of the various advantages of the chemical machining, it has very wide applications ranging from airplane case, panels to the very small sized chip in electronics industry. Some of the important applications of the chemical machining can be highlighted as:

(i) Chemical machining can be used for weight reduction of the components in aerospace applications, forging and casting products, formed sheet metal products to thin down the walls, webs and ribs etc.
(ii) Chemical machining can be applied successfully for the manufacturing of optical encoders, fine filters, flat springs, strain gauges, laminations, chip carriers, step covers, fuel cell plates, heat sinks, shutter blades, fluidic circuit plates, reticles, and drive bands etc.
(iii) Chemical machining can be used to eliminate the decarburized layer from low alloy steel forgings.
(iv) Chemical machining can be applied for the removal of recast layer formed on the product surface that is machined by EDM.
(v) Chemical machining can be used for taking away the sharp burrs formed during conventional machining of complex parts.
(vi) Chemical machining is very much suitable to machining of shallow features like hole and grooves, and mainly for machining shallow cavities of larger surface area.