Chemical Machining

ME688: Advanced Machining Processes
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Classification of Chemical Machining

- **Chemical Machining Processes**
  - **Chemical Dissolution**
    - Chemical Milling
    - Chemical Etching
    - Photochemical Machining
    - Chemical Blanking
    - Chemical Engraving
  - **Electrochemical Dissolution**
    - Electrochemical machining
    - Electrochemical Grinding
    - Electrochemical Drilling
    - Electrochemical Deburring

Only Chemical is used for machining

Introduction

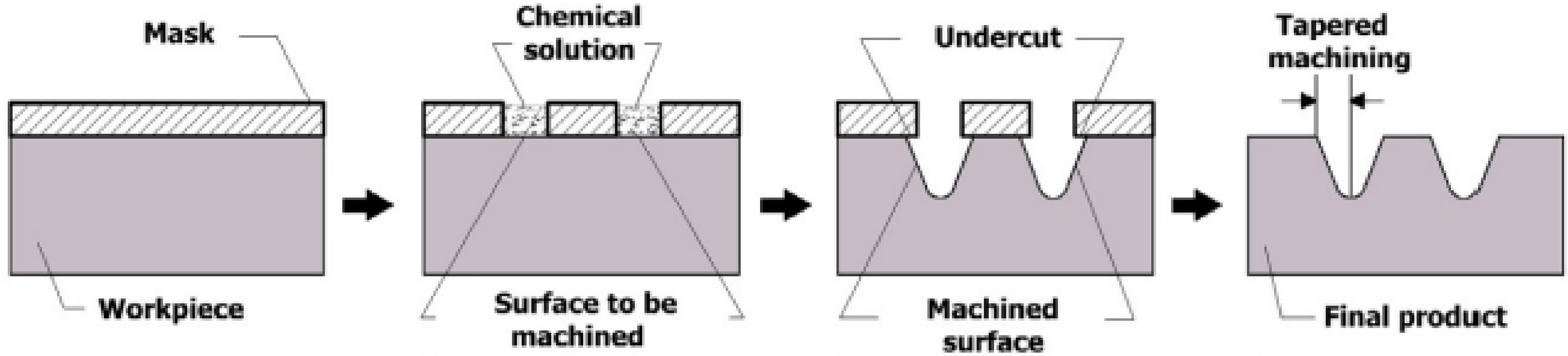
- Chemical Machining (CM) is one the oldest and still useful machining method
- In this process, material is dissolved and removed from the workpiece by controlled chemical reaction using reactive chemical solution
- It has the capability to generate precise and accurate features on workpieces by controlled chemical reactions
- Chemically resistant coatings (or masks) are used to protect the surfaces that are not to be machined
- In ancient times, artisans used the chemical machining method to etch metals.
- But in recent times, CM is widely used for milling of pockets and for generating intricate geometric features where no thermal distortion and cutting forces are concerned

History

- Chemical machining method was initially applied to etch copper jewelry by citric acid in the Ancient Egypt in 2300BC
- Until the 19th century this process was generally used for decorative etching
- In 1826, J.N. Niepce was the first to exploit a photoresist mark for etching pewter (an alloy of 80– 90% of tin and 10–20% of lead)
- William Fox Talbot (1852) patented a method for machining copper with ferric chloride using a photo-resist generated from bichromated gelatin
- In 1888, John Baynes described a process for etching material on two sides using a photoresist
- In 1953, North American Aviation Inc. (California, United States) applied the process to etch aluminum components for rockets. In 1956, the company named the process "chemical milling" and patented it

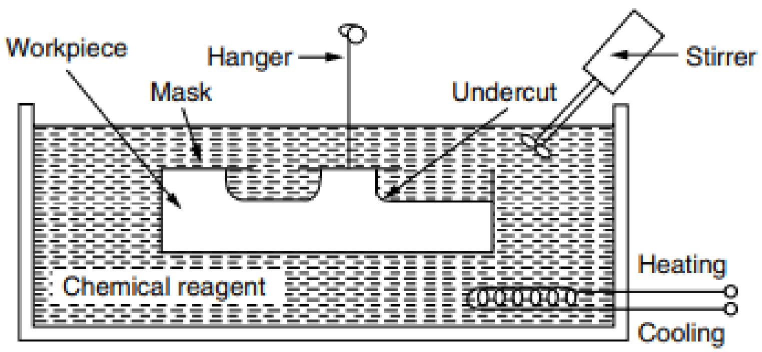
Working Principle

- The material is removed from specified areas of metal workpiece by chemical etching solution like alkaline and acid solutions
- Chemical reagents react with the metal in the solution and produce the required features
- Before machining, the workpiece is cleaned properly and coated with chemically inert maskant apart from the specified areas onto where the etching is to be occurred
- Coating materials allow the chemical solution for dissolving and penetrating the required specified areas of workpiece.

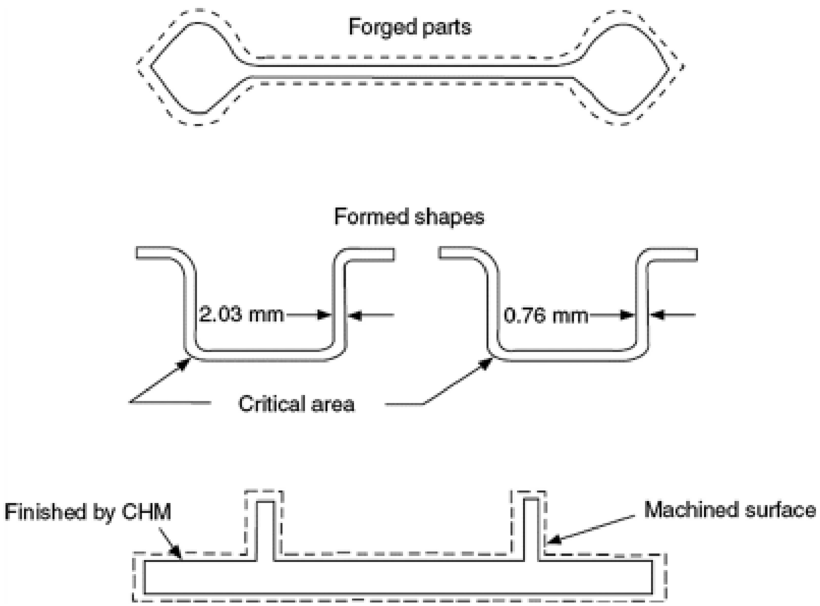


Chemical Machining Process

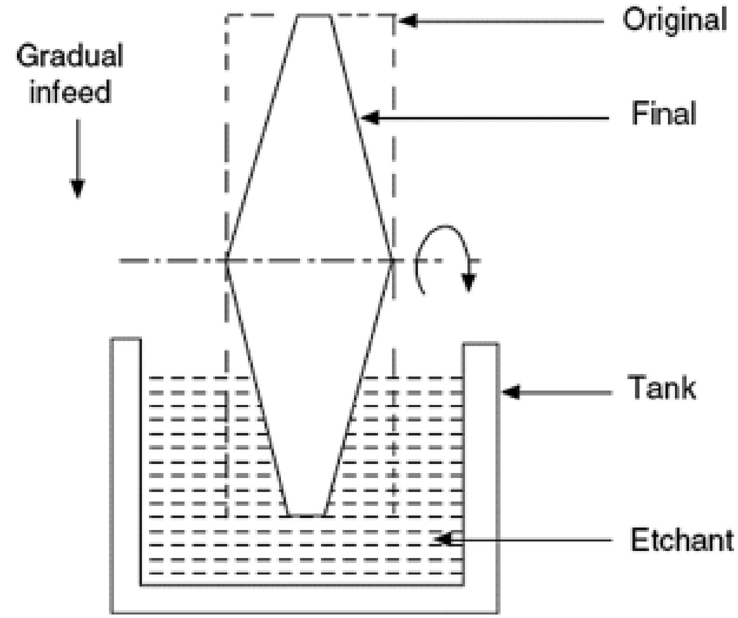
- Chemical milling and chemical blanking are the two most common versions of chemical machining.
- During chemical milling, the material is removed to produce " blind" details (pockets, channels, etc) or to reduce the weight
- During chemical blanking, the details that usually penetrate the material entirely (holes, slots etc) are produced
- This is also the process of blanking complete parts from the sheet by chemically etching the periphery of the desired shape



Chemical Machining Process



Thinning of parts



Production of a tapered disk

Steps for Chemical Machining

Job preparation:

- The workpiece is cleaned properly at the starting of chemical machining process
- The grease, oil, rust, dust or any substance are removed from the surface of workpiece material
- Proper cleaning operation creates the better adhesion bonding between the job and masking material
- Two types of cleaning methods are available, one is chemical and other is mechanical methods
- The chemical method is most extensively used as a cleaning procedure due to it produces less damage comparing to mechanical method

Steps for Chemical Machining

Coating with masking material:

- The insulation operation is carried out in the next step on cleaned workpiece
- The selected coating material must be readily strippable insulation
- Enough adhesion strength to withstand the chemical abrasion during reactions

Scribing of the mask:

- This step is directed by templates to expose the unmasked areas for chemical etching
- The selection of mask material depends upon some specific factors such as the number of parts to be produced, the desired geometry and the size of the workpiece material
- Silk-screen masks are chosen for shallow cuts requiring close dimensional tolerances

Steps for Chemical Machining

Etching:

- This step is the most vital stage to generate the required parts from the workpiece
- The workpiece is immersed into selected etchant and the unexposed areas are machined to produce the required shape
- The etching operation is conducted in the specific temperature which depends on the etched material
- Then the machined workpiece is cleaned for removing the etchant from the machined zone

Cleaning masking material:

- The last step is to remove the masking material from machined workpiece
- Before packaging the finished part, the inspections of the surface quality and dimensions are accomplished

Maskants

- Chemical inert masking material is used to protect workpiece surface from chemical etchant
- Polymer or rubber-based materials are generally used
- Multiple maskant coatings are used to provide a higher etchant resistance
- Maskants should possess the following properties:
  - Tough enough to withstand handling
  - Well adhering to the workpiece surface
  - Easy scribing
  - Inert to the chemical reagent used
  - Able to withstand the heat used during chemical machining
  - Easy and inexpensive removal after chemical machining etching

Maskants

Various maskant application methods can be used such as dip, brush, spray, and electro coating as well as adhesive tapes

- Cut-and-peel masks
- Silk-screen resist
- Photoresist




Etchants

- Etchants are acid or alkaline solutions such as ferric chloride, nitric acid, chromic acid, etc. and are utilized for dissimilar materials for chemical reactions
- Ferric chloride is applied for copper, nickel, aluminum and their alloys
- Ferrous nitrate etchant is utilized for silver
- For chemical machining of titanium, hydrogen fluoride is employed
- Nitric acid is applied for tool steel and chromic acid is used for phosphor bronze

Etchants

- The combined mixture of etchant and material forms surface oxides, which damage the surface finish
- Faster material removal rate reduces the cost of etchant solution
- Due to higher material removal rate, the maskant of workpiece may deteriorate resulting lower surface finish and higher heat generation
- Sometimes, etchant solution removes the corrosion from the workpiece surface
- Some chemical reagents produce good surface finish, however that may diminish the etch depth
- The cost, maintenance and disposal of chemical etchants are also considered during selection of etchant solution in CM

Maskants and Etchants for Different Materials

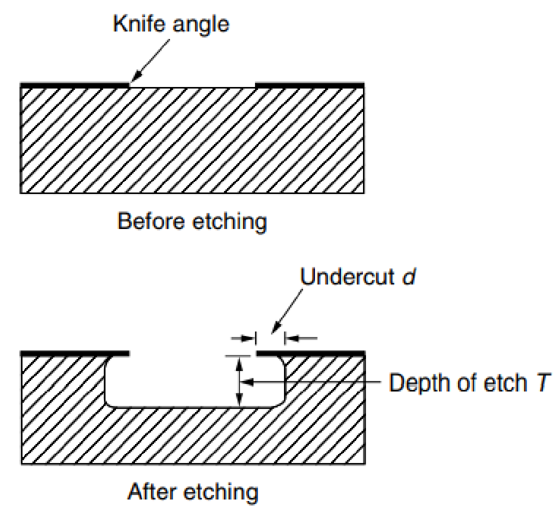
TABLE 3.1 Maskants and Etchants for Different Workpiece Materials

Workpiece	Etchant	Maskant	Etch rate, mm/min	Etch factor
Aluminum	$FeCl_3$	Polymers	0.013–0.025	1.5–2.0
	$NaOH$	Polymers	0.020–0.030	
Magnesium	HNO_3	Polymers	1.0–2.0	1.0
Copper	$FeCl_3$	Polymers	2.0	2.5–3.0
	$CuCl_3$		1.2	
Steel	$HCl:HNO_3$	Polymers	0.025	2.0
	$FeCl_3$		0.025	
Titanium	HF	Polymers	0.025	1.0
	$HF:HNO_3$			
Nickel	$FeCl_3$	Polyethylene	0.13–0.038	1.0–3.0
Silicon	$HNO_3:HF:H_2O$	Polymers	Very slow	

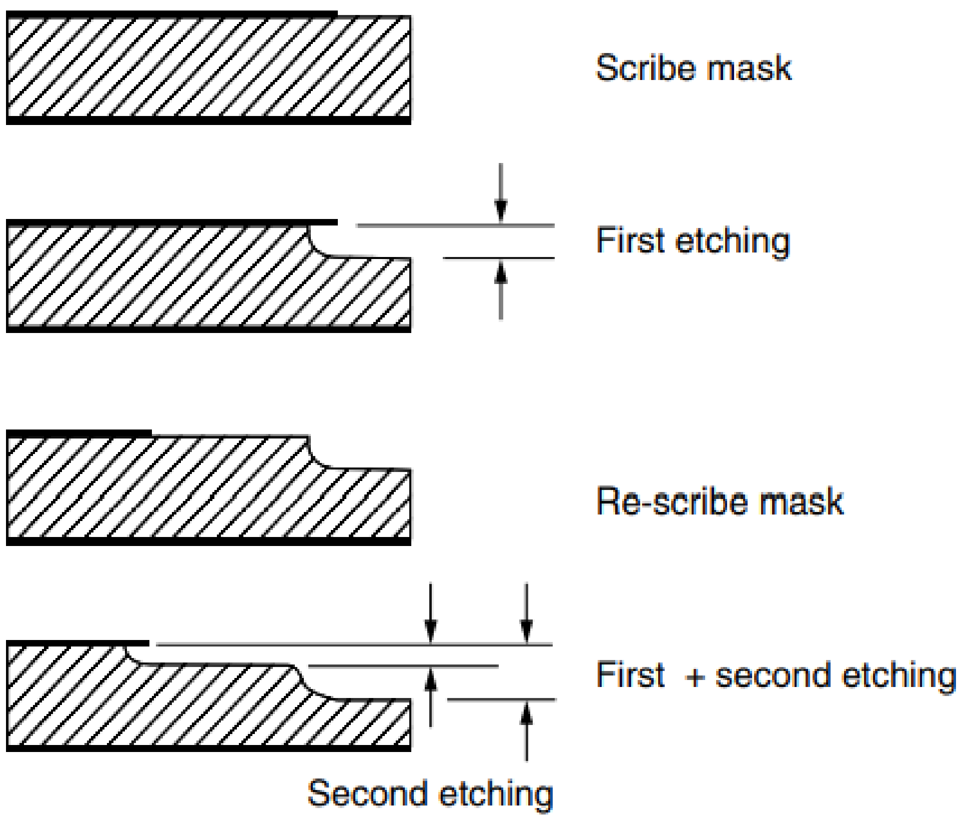
Etch Factor

- When the mask is used, the machining action proceeds both inwardly from the mask opening and laterally beneath the mask thus creating the etch factor
- The etch factor is the ratio of the undercut d to the depth of etch T
- This ratio must be considered when scribing the mask using templates

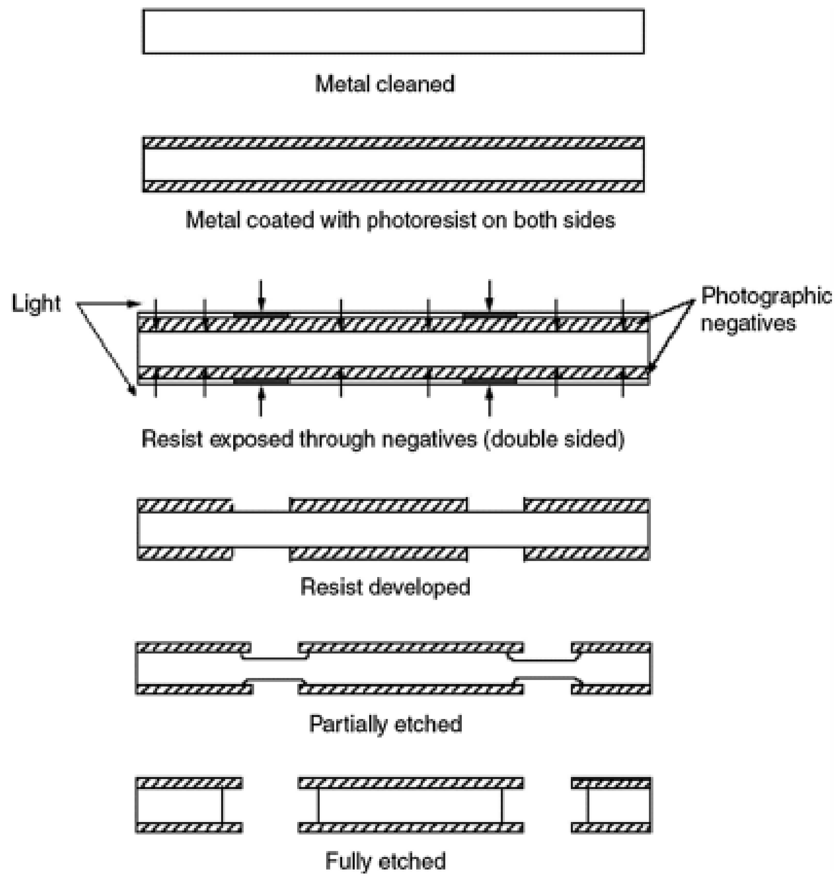
$$Etch\ Factor = \frac{d}{T}$$



Contour Cuts



Photochemical Machining (Spray Etching)



Advantages

- Weight reduction is possible on complex contours that are difficult to machine conventionally
- Several parts can be machined simultaneously
- Simultaneous material removal from all surfaces improves productivity and reduces wrapping
- No burr formation
- No induced stresses thus minimizing distortion and enabling machining of delicate parts
- Low capital cost of equipment, and minor tooling cost
- Quick implementation of design changes
- Less skilled operator is needed
- Low scrap rate

Limitations

- Only shallow cuts are practical
- Deep narrow cuts are difficult to produce
- Handling and disposal of etchants can be troublesome
- Masking, scribing, and stripping is repetitive, time consuming, and tedious
- For best results, metallurgical homogeneous surfaces are required
- Porous castings yield uneven etched surfaces
- Welded zones frequently etch at rates that differ from base metal

Videos

- Photochemical machining
  https://www.youtube.com/watch?v=zJmPgA_aj-k

- Chemical Milling
  - https://www.youtube.com/watch?v=OFYAUAOwrzY
  - https://www.youtube.com/watch?v=C9wPOSsMCTQ

References

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- Hassan El-Hofy, Advanced Machining Processes, McGraw-Hill Prof Med/Tech, 2005
- Helmi Youssef, Non-Traditional and Advanced Machining Technologies, CRC Press, 2020