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Chemical machining

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ABSTRACT

Purpose: Nontraditional machining processes are widely used to manufacture geometrically complex and precision parts for aerospace, electronics and automotive industries. There are different geometrically designed parts, such as deep internal cavities, miniaturized microelectronics and fine quality components may only be produced by nontraditional machining processes. This paper is aiming to give details of chemical machining process, industrial applications, applied chemical etchants and machined materials. Advantages and disadvantages of the chemical machining are mentioned.

Design/methodology/approach: In this study, chemical machining process was described its importance as nontraditional machining process. The steps of process were discussed in detail. The tolerances of machined parts were examined.

Findings: Paper describes the chemical machining process, industrial applications, applied chemical etchants and machined materials.

Practical implications: The machining operation should be carried out carefully to produce a desired geometry. Environmental laws have important effects when chemical machining is used.

Originality/value: The importance of nontraditional machining processes is very high.

Keywords: Machining; Nontraditional machining; Chemical machining; Etchants

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Nontraditional machining processes are extensively employed to produce geometrically complex and precision parts from engineering materials in industries as diverse as aerospace, electronics and automotive manufacturing [1,2]. There are many multiple geometrically designed precision parts, such as deep internal cavities, miniaturized microelectronics and fine quality components may only be manufactured by nontraditional machining processes [3, 4].

Chemical machining is a well known nontraditional machining process is the controlled chemical dissolution of the machined workpiece material by contact with a strong acidic or alkaline chemical reagent. Special coatings called maskants protect areas from which the metal is not to be removed. The process is used to produce pockets and contours and to remove materials from parts having a high strength-to-weight ratio. Moreover, the machining mehod is widely used to produce micro-components for various industrial applications such as microelectromechanical systems (MEMS) and semiconductor industries [5,6].

Chemical machining method may be the oldest nontraditional machining method which is used to shape copper with citric acid in the Ancient Egypt in 2300 BC [7]. Until the 19th century this process was widely used for decorative etching. The development of photography provided a new dimension to chemical machining and in 1826 J.N. Niepce was the first to use a photoresist made from bitumen of Judea asphalt for etching pewter (an alloy of 80-90% of tin and 10-20% of lead). William Fox Talbot (1852) patented a process for etching copper with ferric chloride, using a photoresist made from bichromated gelatin (GB Patent No:565). John Baynes, in 1888, described a process for etching material on two sides using a photoresist which was patented in the USA (US Patent No: 378423).

The main industrial application of chemical machining developed after the war. In 1953, North American Aviation Inc. (California USA) used the process to etch aluminium components for rockets. The company named the process "chemical milling" and patented it (US Patent No: 2739047) in 1956 [8]. The machining method is called in different names such as etching, chemical etching, wet etching, etc.

There are several factors contributing to the popularity of chemical machining processes as follow [9]:

a. Chemical machining process is mature and well established.
b. It is simple to implement.
c. There is no additional cleaning step needed.
d. Cheaper machining process.

In this study, chemical machining process was described its importance as nontraditional machining process. The steps of process were discussed in detail. The tolerances of machined parts were examined. Finally the environmental effect on chemical machining was mentioned.

2. Steps of chemical machining

Chemical machining process has several steps for producing machine parts. These are given below:

1 Workpiece preparation: The workpiece material has to be cleaned in the beginning of chemical machining process. The cleaning operation is carried out to remove the oil, grease, dust, rust or any substance from the surface of material. A good cleaning process produces a good adhesion of the masking material. There are two cleaning methods; mechanical and chemical methods. The most widely used cleaning process is chemical method due to less damages occurred comparing to mechanical one. Ultrasonic cleaning machine is applied with using special cleaning solution and heating is beneficial during the cleaning process.

2 2. Coating with masking material: The next step is the coating cleaned workpiece material with masking material. The selected masking material should be readily strippable mask, which is chemically impregnable and adherent enough to stand chemical abrasion during etching.

3 3. Scribing of the mask: This step is guided by templates to expose the areas that receive chemical machining process. The selection of mask depends on the size of the workpiece material, the number of parts to be produced, and the desired detail geometry. Silk-screen masks are preferred for shallow cuts requiring close dimensional tolerances.

4 4. Etching: This step is the most important stage to produce the required component from the sheet material. This stage is carried out by immerse type etching machine (Fig 1). The workpiece material is immersed into selected etchant and the uncovered areas were machined. This process is generally carried out in elevated temperatures which are depended on the etched material. Then the etched workpiece is rinsed to clean etchant from machined surface.

5 5. Cleaning masking material: Final step is to remove masking material from etched part. The inspections of the dimensions and surface quality are completed before packaging the finished part.

3. Maskants

Masking material which is called maskant is used to protect workpiece surface from chemical etchant. Polymer or rubber based materials are generally used for masking procedure. The selected maskant material should have following properties [6].

1. Tough enough to withstand handling
2. Well adhering to the workpiece surface
3. Easy scribing
4. Inert to the chemical reagent used
5. Able to withstand the heat used during chemical machining
6. Easy and inexpencive removal after chemical machiningetching

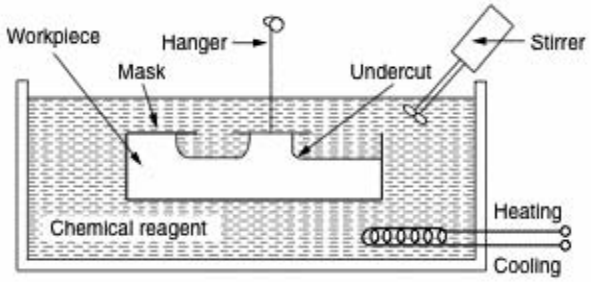

Fig. 1. Typical chemical machining set-up [6]

Multiple maskant coatings are used to provide a higher etchant resistance. Long exposure time is needed when thicker and rougher dip or spray coatings are used. Various maskant application methods can be used such as dip, brush, spray, roller, and electrocoating as well as adhesive tapes.

When higher machined part dimensional accuracy is needed, spraying the mask on the workpiece through silk screen would provide a better result. Thin maskant coating would cause severe problems such as not withstanding rough handling or long exposure times to the etchant. The application of photoresist masks which are generally used in photocehmical machining operation, produce high accuracy, ease of repetition for multiple-part etching, and ease of modification. Possible maskaint materials for different workpiece materials were given in Table 1.

Table1.
Masking materials for various chemical machined materials [5, 6]

Workpiece material	Masking material
Aluminium and alloys	Polymer, Butyl rubber, neoprene
Iron based alloys	Polymer, Polyvinyl chloride, Polyetilien butyl rubber
Nickel	Neoprene
Magnesium	Polymer
Copper and alloys	Polymer
Titanium	Polymer
Silicon	Polymer

4. Etchants

Etchants are the most influential factor in the chemical machining of any material. Various etchant are available due to workpiece material. The best possible etchant should have properties as follow [5, 6, 9-12]:

Table 2.
Properties of chemical etchants, concentrations, etching temperatures for various materials in chemical machining [5, 6]

Material	Chemical etchant	Concentration	Etching Temperature (°C)	Etch rate (mm/min)
Aluminium and alloys	$FeCl_3$	12-18 ^{0} Bé (*)	49	0.013-0.025
Copper and alloys	$FeCl_3$	42 ^{0} Bé	49	2.0
	$CuCl_2$	35 ^{0} Bé	54	1.0
	Alkaline etchants	---	50	---
Steel	$FeCl_3$	42 ^{0} Bé	54	0.025
Nickel	$FeCl_3$	42 ^{0} Bé	49	0.13-0.38
Titanium	HF	---	--	1.0
Magnesium	HNO_3	% 12-15	32-49	1.0
Glass	HF	---	---	---
	$HF+HNO_3$	---		
Silicon	HNO_3+HF+H_2O	---	38-49	Very slow

*(The calculation of Baumé [Bé] value is Bé = 145 [(sg-1)/sg] sg: specific gravity)

a. High etch rate
b. Good surface finish
c. Minimum undercut
d. Compatibility with commonly used maskants,
e. High dissolved-material capacity
f. Economic regeneration
g. Etched material recovery
h. Easy control of process.
i. Personal safety maintenance

Different etchants are commercially available or the required etchant can be prepared in shop. Ferric chloride ($FeCl_3$) is the most widely used etchant in chemical machining. It is mainly used for etching iron-based alloys as well as copper and its alloys, aluminium, etc. Cupric chloride ($CuCl_2$) is generally applied for copper and copper based alloys in electronics industry because various regeneration systems are available for the waste etchant. Alkaline etchants are introduced to the fabrication of electronic components such as printed circuit board.

There are some other etchants can be named, but the industrial application of chemical machining is generally used these three etchants, even most of the companies use only ferric chloride due to economical considerations (Table 2).

5. Advantages and disadvantages of chemical machining

The application of chemical machining provides several advantages as follow [5, 6, 9-12]:
1. Easy weight reduction
2. No effect of workpiece materials properties such as hardness
3. Simultaneous material removal operation
4. No burr formation
5. No stress introduction to the workpiece
6. Low capital cost of equipment
7. Easy and quick design changes
8. Requirement of less skilled worker
9. Low tooling costs
10. The good surface quality
11. Using decorative part production
12. Low scrap rates (3%).

Hovewer, chemical machining has also some disadvantages [5,6,9-12]:
1. Difficult to get sharp corner
2. Difficult to chemically machine thick material (limit is depended on workpiece material, but the thickness should be around maximum 10 mm)
3. Scribing accuracy is very limited, causes less dimensional accuracy
4. Etchants are very dangerous for workers
5. Etchant disposals are very expensive

6. Environmental issues

Environmental issues in chemical machining operations may be the most important factor affects the machining process should be used or not. Most of the chemicals such as cleaning solutions, etchants, strippers etc. are very hazardous liquids. Therefore handling and disposal of them are very costly.

Industrial trend of using these chemicals are to select more environmentally accepted ones for chemical machining process. Moreover, regeneration of waste etchant and etched metal recovery from waste etchants have been studied and there could be a suitable regeneration/recovery systems for some etchants like $FeCl_3$, $CuCl_2$ and alkaline etchants [13-17].

7. Conclusions

Chemical machining is widely used to produce complex machine parts for various application as well as decorative parts. The machining operation should be carried out carefully to produce a desired geometry. Environmental laws have important effects when chemical machining is used.

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