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Utilizing Chemical Machining Methods in the Metalworking Sector

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Abstract

Chemical machining is a kind of material removal technique used to produce desired shapes and dimensions by selectively or completely removing material through carefully regulated chemical attack using etchant solutions, which are solutions of acids or alkalis. One type of chemical machining is chemical milling, also known as contour machining, etching, or chemiluminescence. The aerospace industry uses chemical milling to remove thin layers of material from extruded parts for aircraft frames. large aircraft components, and missile skin panels. While the component is removed by chemical dissolution rather than shearing, chemical in nature blanking is similar to blacking sheet metal in that it is used to create capabilities that pierce throughout the material's extra thickness. Chemical blanking is commonly utilized in the burr-free etching of electronic devices, decorative panels, thin sheet metal stampings, and intricate or tiny shape production. The process of photochemical processes blanking is also known as photo etching. It's an adaptation of chemical grinding. Usually, photographic processes are used to remove material from a thin, flat sheet. Fine screens, printed circuit boards, electric motor laminations, flat springs, and color television masks are among the common uses for sunlight blanking. One of the most recent and effective methods of removing metal from materials is electrical machining, which involves carefully dissolving an electrolytic cell's anode. Metals and alloys that are tough or hard to machine through electromechanical machining are especially well suited for this method of fabrication. The electrochemical machining (ECM) process is primarily used in the machining of hard-heat-resistant alloys, in the insertion of holes, in the creation of cavities in forging dies, and in the grinding of complex external shapes such as those of turbine blades, aerospace components, tungsten carbide, and alloy steel nozzles. The uncommon machining processes—chemical milling, chemical blanking, photochemical blanking, and electrochemical machining—that have been pointed out above are covered in this overview article. Additionally, the process variables for the aforementioned chemical machining processes methods and uses are described.

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INTRODUCTION TO CHEMICAL MACHINING TECHNIQUES

Higher hardness and strength materials cannot be satisfactorily machined using traditional ways of machining. Normal machining steps have not met the requirements for surface finish and tolerances. Chemical reactions machining processes were developed as a result among these requirements. Based on the discovery that chemicals attack and inscribe metals to one another removing minute amounts of material from the metal surface, chemical machining techniques were created. Chemical reagents and etchants, such as acids and alkaline solutions, are used to carry out this process through chemical dissolution. The earliest unconventional machining method is chemical machining, which has been applied to deburr, etch metals, alloys, and hard stones, as well as more recently, to the production of microprocessor chips and electronic circuit boards. Chemical milling is a traditional subtractive machining technique where material is removed to create the desired shape using baths of temperature-controlled etching compounds. It is described as the process of causing a material to corrode chemically in order to create blind features consisting of channels and pockets. This process reduces weight quickly, requires less skilled labor, and has lower capital and tooling costs than other machining techniques. It not only makes design modifications simple to execute, but it also spares the metal from extra stresses. Figuratively produced by mechanical motion blanking presses, the chemical blanking process is a well-known nontraditional machining method for producing machined features on thin plates and foil material using an appropriate removing material solution. The material surface is cleaned in the preliminary processing by grinding, degreasing, and the process of pickling The process of creating a part from thin sheet metal by chemically etching the desired shape's perimeter is known as chemical in nature blanking. Chemical dissolution is used for getting rid of the material. Parts that are normally made from thin plates and foil material by mechanical blanking presses are instead blanked chemically. Using a photo resist and etchants to corrosively machine separate specific areas, photochemical machining—also referred to as photochemical milling or photo etching—is a chemical milling process used to fabricate sheet metal components. Another name for photosynthesis blanking is photo etching. It's a tweak on chemical grinding. Thin measure metal parts can be made by the photochemical processes machining process. Depending on the kind of metallic materials, thickness ranges from .001" to .080". A stencil known as a “photo tool” is used in the photochemical processes machining process to expose multiple images of the parts that need to be created onto both sides of a raw material sheet that has been coating with “resist,” an acid- and light-resistant substance. The metallic substance surrounding the part is dissolved using an etching chemistry once the images of the parts have been developed and the uncured “resist” has been removed. One of the most sophisticated alternative manufacturing techniques, electrochemical machining (ECM) is used to machine alloy materials with high ductility while hardness. It might be helpful in producing highly precise smaller-sized components. The highly precise parts with micro-sized holes, different kinds of slots, and diverse surfaces are highly desired for mission-critical applications such as nuclear power plants, the aerospace industry, the electronics industry, and the medical profession [1–4].

METHOD OF CHEMICAL MILLING

One type of chemical machining is chemical milling, also known as contour machining, etching, or chemilling. Chemical milling is primarily used to remove metal components from relatively large surface areas, either completely or selectively to create shapes. The primary goal is to create intricately profiled shallow tooth decay on plates, sheets, and forgings, usually with the intention of reducing size overall. This method has been applied to a wide range of metals, removing metal to depths of up to 12 mm [5].

Chemical milling entails four steps:

- Cleaning.
- Masking.
- Etching.
- De-masking.

Procedure for chemical milling:

- After chemical milling, the parts' stresses need to be released to avoid warping.
- To guarantee even material removal and strong masking material adhesion, the surfaces are properly cleaned and degreased.
- Afterwards, the masking material is used.

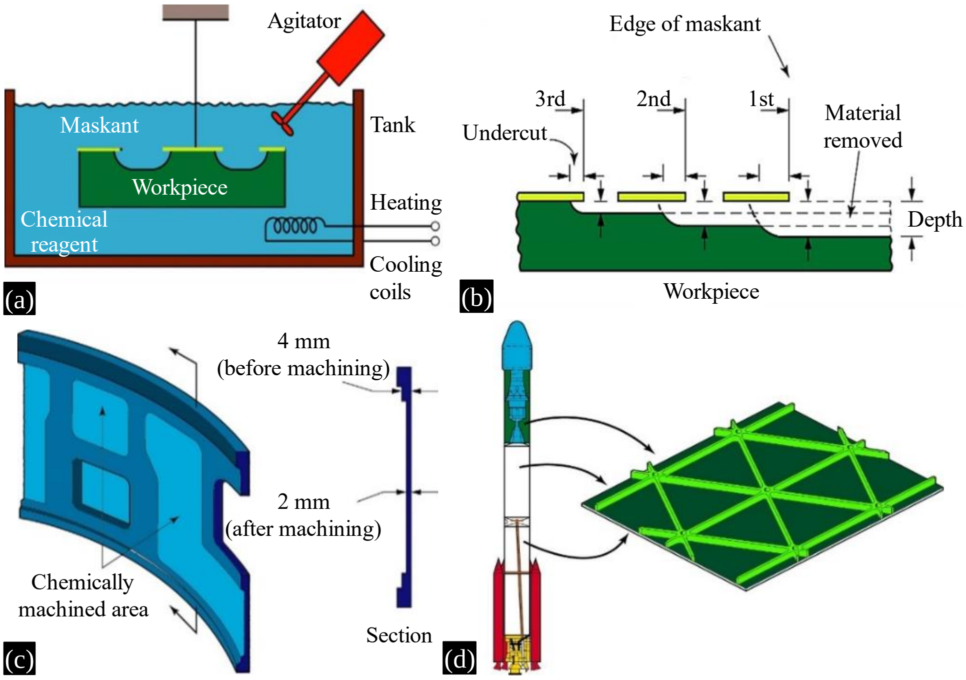

Figure 1. Chemical milling operation.

- Although elastomers (rubber and neoprene) and plastics (polyvinyl chloride, polyethylene, and polystyrene) are also used, masking with tapes or paints (maskants) is a common practice.
- The chemical reagent and maskant material shouldn't react.
- When needed, the scribe-and-peel method is used to peel off the maskant covering different areas that need to be etched.
- Chemical etchants, like sodium hydroxide for aluminum, hydrochloric and nitric acid solutions for steel, or iron chloride for stainless steel, are utilized to machine the exposed surfaces.
- To ensure a consistent depth of material removal during chemical milling, temperature regulation and stirring are crucial.
- To avoid any further reactions or exposure to etchant residues, the parts need to be thoroughly cleaned after machining [6].
- After removing the remaining masking material, the part is cleaned and examined.
- The reagent has no effect on the masking material; instead, a different kind of solvent usually dissolves it.
- Chemically milled parts may undergo different processes for finishing.

You can create different contours and stepped cavities by repeating this series of operations. The chemical milling process schematics and some of the parts produced are displayed in Figure 1.

Reagent tanks can have a maximum size of 3.7 m by 15 m. Wet etching is a common term for this process, which is used to create microelectronic mobile phones. Chemical milling could result in some surface damage due to intergranular bombardment and preferential etching, which negatively impact surface characteristics. Uneven material removal can occur when brazed and anchored structures are chemically milled [7, 8].

CHEMICAL BLANKING OPERATION

While the material is removed by chemical dissolution rather than shearing, chemical blanking is identical to blanking metallic sheet in that it is used to create features that pierce through the material's thickness. Other names for chemical blanking include photo forming, photo fabrication, and pictures etching. Through chemical reaction, the metal is completely removed from specific areas in the course of this procedure. The sheets and foils are the main materials used in the process. This method works with almost any metal, but it is not advised for material thinner than 2 mm.

Procedure for chemical blanking is explained step by step:

- Using acid or alkalis, the work piece is cleaned, degreased, and pickled.
- After the metal has been cleaned and dried, photoresist material is sprayed, whirled coated, or dipped onto the work piece.
- After that, it is dried and cured.
- In photo resist materials, the technique of photography has been appropriately utilized to generate images that are resistant to etching.
- This kind of maskant is not affected by room light; instead, it is sensitive to a specific frequency of light, typically ultraviolet light.
- Similar to developing film, this surface is now exposed to light through the negative, which is a photographic plate of the necessary design.
- The image is developed after it has been exposed.
- During the developing process, the parts that are not exposed dissolve away, revealing the bare metal.
- After that, the cleaned metal is either dipped into the solution or sprayed with a chemical etchant using a machine.
- One of the various chemicals or hydrofluoric acid (for titanium) could be used as the etching solution.
- The completed part is ready for instant rising to remove the etchant after the undesired metal has been eaten away, which takes one to fifteen minutes.
- Printed circuit boards and complex design blanking can be appropriately produced through chemical blanking with photo resist maskants.
- The advantages of this process are summarized below:
  - Very thin material (0.005 mm) can be suitably etched.
  - High accuracy of the order of plus or minus 0.015 mm can be maintained.
  - High production rate can be met by using automatic photographic technique.

PHOTOCHEMICAL BLANKING

- Another name for the photochemical blanking is photo etching. It's a tweak on chemical grinding. Usually from a brittle and flat sheet, material is removed using photography techniques. Metals as thin as 0.0025 mm can be blanked to create intricate, burr-free shapes. This method is also used for etching and is occasionally referred to as photochemical machining [9]. A comprehensive description of the photochemical processes freezing procedure is given.
- The part that needs to be blanked is designed at a magnification of up to 100 x.
- A photographic negative is then created and sized down to the final part.
- Artwork refers to the design's reduced negative.
- The original (enlarged) drawing permits the amount of reduction (e.g., 100 x) for inherent design mistakes to be eliminated for the final artwork image.
- One method of applying a photosensitive material (photo resist) to a sheet blank is dipping, spraying, spin casting, or roller coating; the material is then dried in an oven. We refer to this coating as an emulsion.
- The glazed blank is covered with the negative, which is then exposed to UV light, hardening the exposed areas.
- The inaccessible areas are dissolved when the blank seems developed.
- The exposed portions of the blank are removed by either spraying it with the reagent or submerging it in a reagent bath, similar to chemical milling.
- After removing the masking substances, the part is thoroughly cleaned to get rid of any remaining chemical residue.

Photochemical processes blanking is commonly used in flat springs, printed circuit boards, electric motor laminations, fine screens, and color television masks. Despite the need for skilled labor, the process can be automated and costs for tooling are minimal. When producing in medium to large quantities, this method is cost-effective.

Electrochemical Machining

One of the newest and most effective machining techniques for removing metal is electrochemical in nature machining, which involves carefully dissolving an electrical cell's anode. This method works especially well with metals and alloys that are hard or impossible to machine through mechanical means. The theories of Michael Faraday's classical legislation of the process of electrolysis serve as the foundation for the working principle, which essentially calls for two electrodes, an electrolyte, a gap, and a source of D.C. power with enough capacity. ECM is essentially the electroplating method in reverse [10]. With this technique, almost any conducting material can be machined. It is impossible to remove material that is not conductive. In Figure 2, a schematic drawing of the ECM procedure is displayed. A step-by-step explanation of the electrochemical machining process is provided.

- The cathode is actually tool-shaped during the process, resembling the completed work piece's mirror image.
- The positive supply is linked to the work piece.
- The electrolyte, which completes the electrical circuit between the anode and cathode, advances the tool, or cathode, toward the anode (work piece), when it is connected to the negative terminal. Metal is then removed from the work piece through electrical action and the cathode (tool) shape is reproduced on the work piece.
- In order to generate current and transfer heat between the work piece and the tool, the electrolyte bath must be pumped at high pressure through the gap and rotated at a fast enough pace.
- The cathode's electrolysis process releases free hydrogen and negatively charged hydroxyl ions.
- These hydroxyl ions mix with the anode's metal ions to form insoluble metal hydroxides, which removes the material from the anode.
- As a result of this process, the cathode (tool) continues to take on its original shape in the power source work piece (anode).
- Because there is no direct friction created by the tool's contact with the construction piece, it cannot break down or accumulate heat.

The electrolyte, cathode tool, anode work piece, and D.C. power supply are a few crucial ECM components. Between the tool and the work piece, there is a 0.05 to 0.70 mm gap. The electric current is of the order of 50 to 40000 Ampere at 5 to 30 V D.C. for a current density of 20 to 300 Ampere/Square cm. The electrolyte is driven by an inlet pressure of 20 (kgf/cm^2) to flow through this gap at a rate of

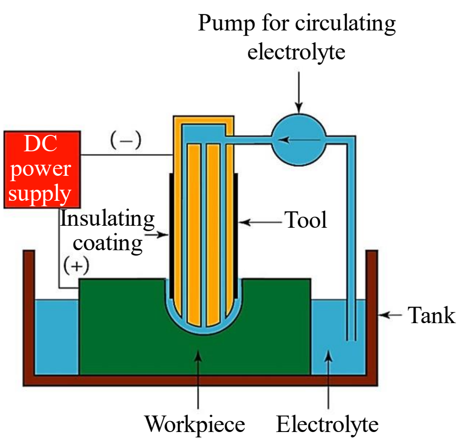

Figure 2. Electrochemical machining operation.

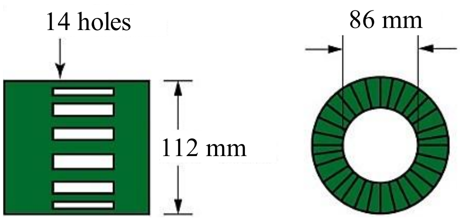

Figure 3. Components produced by ECM, Electrochemical Machining process.

30 to 60 meters per second. By filtering, centrifuging, or setting the electrolytes, suspended solids are eliminated, and the filtered electrolyte is then recycled for further use.

General requirements on the tool material in ECM are mentioned below:
- The substance that's used for the tool needs to be an effective electrical conductor.
- Because of the pressure of the liquid, it should be sufficiently rigid to support the load.
- It ought to possess no chemical reaction with the electrolyte.
- It should be simple to machine into the required shape.
- When the mineral potassium or sodium is used as the electrolyte, the most often used electrode materials are copper, brass, titanium, copper-tungsten, and stainless steel.
- The following materials can also be used as tool materials: tungsten carbide, platinum, bronze, graphite, and aluminum.
- The exact replica of the application's shape is achieved by creating a cavity or hole. Consequently, the accuracy of the work piece is directly impacted by the technique's shape accuracy.

Factors govern the accuracy of parts produced by ECM:
- Machining Voltage
- Feed rate of the electrode (tool)
- Temperature of the electrolyte
- Concentration of the electrolyte

These days, electrochemical in nature machining systems can be found as numerically managed machining processes centers that can maintain tight tolerances for dimension while producing at high rates of efficiency. Figure 3 displays a selection of the parts that ECM manufactures.

MRR (Metal Removal Rate), is a crucial ECM parameter. The laws of electrolysis established by Faraday control the total machining rate. assuming that the intended metal removal process makes use of all the current passing through the electrolytic cells. The rate of metal removal is determined in terms of the length of the removed layer under steady state flow conditions with 100% current efficiency. Sharp square corners and spongy bottoms are not well suited for electrochemical in nature machining due to the electrolyte's propensity to erode away sharp profiles. It could be challenging to regulate the electrolyte flow, which could make it difficult to create irregular tooth decay with the appropriate dimension. It is important to include a small taper in designs so that holes and cavities can be machined. The shaped tool should be composed of brass, copper, bronze, or stainless steel and should have a solid or tubular shape. The tool needs to be easily machined into the required shape and stiff enough to support the load caused by fluid pressure. The accuracy of the tool's shape directly influences the accuracy of the work piece. The aforementioned technique can be used to machine almost any conducting material under the right circumstances and with tooling that is properly designed. When compared to traditional machining methods, the substrate removal rate for high strength-temperature-resistant (HSTR) materials is fairly high using this approach. Extremely thin metal sheets can be worked with ease and without distortion, and tool wear is almost nonexistent. Additionally, it is utilized for the machining of gears and engine castings for automobiles. Additionally, it is employed to create tiny holes and to machine and finish forging die cavities (die sinking). This process is used in various forms for drilling, trepanning, turning, facing, milling, slotting, and profiling, as well as for making continuous aluminum strips and webs. The electronics industry production micromachining is one of the more recent uses of ECM.

CONCLUSION

Complex shapes and contours as well as hard materials lend themselves well to chemical substances machining techniques. They don't generate residual stresses, forces, or high temperatures. Uneven surfaces from chemical milling of castings can be a result of the material's porosity and nonuniformity. At relatively shallow depths of cut, accuracy within the range of plus or minus 0.01 mm can be attained with optimal control over time, temperature, and solution. It is possible to obtain an outermost finish of about 5 microns. Better surface finish, on the order of 1.6 microns, is seen in aluminum alloys. An aluminum component's aluminum removal rate is said to be 140 cubic centimeters per minute. Chemical blanking is commonly used for producing intricate or tiny shapes, as well as for burr-free etching from printed circuit boards, decorative panels, and thin sheet metal stampings. Where conventional blanking dies are difficult to produce, photochemical processes blanking can create very small parts. The method works well for blanking delicate substances and producing pieces as well. To safeguard employees from exposure to both liquid and highly volatile substances, controlling chemical reagents calls for extra safety measures and precautions. Essentially some the manufacturing process's outcomes can be recycled, one of the main disadvantages is the disposal of chemical contaminants. Specific tolerances of less than or equal to 0.02 mm can be maintained by ECM. Forgiveness can typically be kept within the range of plus or minus 0.02 to 0.04 mm on a production basis. The ECM process is primarily used in the machining of hard-heat-resistant alloys, in the drilling of holes, in the creation of cavities with forging dies, and is known as machining of complex external shapes such as those of turbine blades, aerospace components, tungsten carbide, and alloy steel nozzles. In view of the strict specifications needed for developing MEMS (Micro-Electro-Mechanical Systems) and computer chips, electrochemical machining processes are becoming more and more significant.

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