PHOTO CHEMICAL MACHINING (PCM) – AN OVERVIEW

DEFINITION

Photo chemical machining is an engineering production technique for the manufacture of burr free and stress free flat metal components by selective chemical etching through a photographically produced mask.

This document has been created to briefly explain the fundamentals of the PCM process, when applied to the manufacture of mechanical components. It is aimed at product designers and specifiers who would like to understand more about the science and technology of etching without having to delve too deeply into the chemistry.

Qualitetch Components hope that the text achieves this aim, but should you require a more detailed explanation please contact our technical department.

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PHOTO CHEMICAL MACHINING – A BRIEF PROCESS HISTORY

The development of knowledge of acid attack upon metals is not new, its origins lie in antiquity. Legend tells that the ancient Greeks had discovered a fluid, which is referred to as liquid fire, that attacked both inorganic and organic materials. However as this was the Bronze age it is unlikely that they possessed the technology to manufacture such an acidic chemical. The ancient Egyptians etched copper jewellery with citric acid as long ago as 2500BC. The Hohokam people, of what is now Arizona, etched snail shell jewellery with fermented cactus juice around 1000BC.

Chemical etching was not used regularly in Europe until the fifteenth century when it was used to decorate suits of armour. Engraving was impossible since armour was forged as hard as the chisels of the day. The earliest reference to this process describes an etchant made from common salt, vinegar and charcoal acting through a hand scribed mask of linseed oil paint. Decorative patterns where also etched into swords by means of scribed wax resist. These techniques were adapted and improved by etchers operating in close co-operation with armourers until, by the seventeenth century, armour had become wholly ceremonial and great works of etched art.

The sixteenth century saw the use of etching techniques to produce printing plates of a superior quality to those previously engraved. The main advantage being the lack of burrs. During the mid seventeenth century etching was used for the indelible calibration of measuring instruments and scales such as an artillery gunners conversion table etched around 1650. This related the bore of a cannon in relation to the weight of the shot and assisted in the estimation of its trajectory.

Two developments within the space of forty years in photography laid the foundations for the photoresists we use today. In 1782 John Senebier of Geneva investigated the property of certain resins to become insoluble in turpentine after exposure to sunlight. Inspired by this, Joseph Nicephore Niepce resurrected an ancient Egyptian embalming technique that involved the use of what is now known as Syrian asphalt. This hardens after exposure to several hours of sunlight, into an acid resistant film. However, it took constant experimentation until this development was a success in 1822. The result was a resist that could be photo-polymerised in the exposed areas whereas the unexposed areas could be developed off in a solution of oil of lavender in turpentine. The age of photo etching had arrived.

By 1925 the huge daily newspaper industry made large-scale use of printing plates etched in nitric acid solution. By 1927 the use of chemical milling through a rubberised paint mask, which was hand cut around a template, was being used as an engineering production tool.

John Snellman may have been the first to produce flat metal components by photo chemical machining of shim stock that was too hard for punching. He innovated the use of cutting lines, or outlines, in the photoresist mask. This ensured even simultaneous etching of every component detail and also his use of tabs secured the parts into the parent metal sheet. He patented the process in 1944 whereafter it was increasingly used to manufacture shims, springs, stencils, screens and virtually any complex shape which for technical reasons could not be punched. Within ten years two American companies, the Texas Nameplate Company and the Chance-Vought Aircraft Corporation had taken a considerably refined Snellmans process and renamed it Chemi-Cut.

The photo chemical machining process was further developed on both sides of the Atlantic, becoming a production process in the UK in the early 1960s. Development was further accelerated by the introduction in commercial applications of the printed circuit board. The high volumes required for this product saw large strides in development, particularly in the design of etching equipment. These improvements quickly transferred to the photo chemical machining process, leading to the industry we see today.

METALS SUITABLE FOR THE ETCHING PROCESS

METAL TYPES

Most metals are suitable for the etching process. The method of production and the chemical composition both have a bearing on the rate of processing, the overall finished size, tolerance and the appearance of the etched edges. Some alloyed materials do cause particular problems to the process e.g. a high carbon content contaminates the etching chemicals unless filtered out at the processing stage (refer to the rate of etch). Silicon causes particular problems with both the etching rate and adhesion of the photoresist to the surface of the material (refer to metal preparation). Metals that have an alloying content of Cobalt, Palladium or Titanium have to be given careful consideration. These three alloys especially can be a major factor in preventing a successful etch. Alternative etching chemistry can be used to etch Titanium. However, as most commercial etching machines use Titanium for the metallic components within, a successful Titanium etch equates to a wrecked machine. Precious metals can be successfully processed, but as special chemistry is required most commercial etching companies do not process these metal types unless the volume is high enough to warrant the special conditions. The majority of metal processed is cold rolled stock. However, sintered metals such as Molybdenum can be successfully processed. Pre-plated materials are generally not processed as the etch rate of the plating metal will differ from the base metal. This could consequently cause tolerance problems and cut back the plated finish to unacceptable levels. Consequently plated components are etched and post plated.

SPECIFIC METAL REQUIREMENTS FOR THE PROCESS

The quality of the metal used for the process is always purchased as photo etch quality rather than standard commercial grade. The metal is cold rolled, high precision, especially in relation to the tolerancing of the thickness of gauge. It also has a superior surface finish to standard commercial grade material. Although there are slight variations between metal types, the general rule for thickness tolerance is ± 8% material thickness. It is very rare that precision strip deviates to this tolerance band and the normal deviation in the ‘as rolled condition’ is within ± 4% of metal thickness. Surface finish varies according to metal type and condition. However the surface finish is always superior to standard commercial grade material stock.
The raw material for processing is received in three forms; flat sheets, coil and specific size cut blanks. Sheet material, which is usually supplied in 600mm x

1200mm or 2000mm x 1000mm, is confined to thicker gauge copper and brass (including and above 0.4mm), aluminium and annealed stainless steel (0.6mm upwards). This material can be supplied with the surface polycoated to prevent surface damage during transport/handling. There are no specific problems with sheet material provided the suppliers handle it with care and it is stored in an appropriate manner prior to processing.

TYPICAL MILL STOCK

METAL TYPE	0.013mm - 0.1mm	0.1mm –0.3mm	0.3mmn – 0.5mm	0.7mm – 1.00mm	1.00mm – 1.60mm
Aluminium	Special Order	Coil	Coil & Sheet	Sheet	Sheet
Beryllium Copper	Coil	Coil	Coil	Coil	Coil
Brass	Coil	Coil	Sheet	Sheet	Sheet
Copper	Coil	Coil	Coil & Sheet	Sheet	Sheet
Mild Steel	Coil	Coil	Coil	Coil	Coil
Nickel	Coil	Coil	Coil	Coil	Coil
Phosphor Bronze	Coil	Coil	Coil	Coil	Coil
Spring Steel Annealed	Coil	Coil	Coil	Coil	Coil
Spring Steel Hard & Tempered	Coil	Coil	Coil	Coil	Coil
Sandvik Steel	Special Order	Coil	Coil	Coil	Special Order
Stainless Steel Spring Temper	Coil	Coil	Coil	Coil	Not readily Available
Stainless Steel	Coil	Coil	Coil	Coil & Sheet	Sheet
Transil	N/A	N/A	0.35mm only Coil	N/A	N/A

METAL FROM COILS

After the rolling process, the edges of the coil are slit to remove the wavy edge caused by this process. Stainless Steels have to undergo a further tension levelling (or stretch band levelling as it is often called) process. This removes any curvature across the width of the strip and along its length. However because the process is a de-coil and then re-coil operation, the characteristic of coil set is not alleviated. Coil set, which results in the material having a degree of curvature along the length of the cut sheet, is minimised by ensuring the re-coil operation is performed on coil centres that have a minimum diameter of 300mm. BS 5770 Part 4 refers to allowable curvature for Stainless Steels and although the standard is acceptable for commercial grade materials, the flatness required for photoetch must be superior to the standard. Although flatness tolerances are proportional to the thickness of the metal, a general rule of thumb is a maximum flatness deviation of less than 2% of the length of the cut sheet is a minimum requirement. Coil set is more pronounced in softer, thicker materials and special care has to be taken when these materials are sourced e.g. 1mm thick mild steel (low carbon steel) in the annealed state (105 v.p.n. max) would typically have a curvature of 30mm over a 500mm sheet length. That is if both ends were placed on a flat surface with the concave face downwards, the highest point of the curvature above the flat surface would typically be 30mm. This would make printing of the sheet (refer to image creating) with the required accuracy very difficult, if not impossible.

Cut Blanks are materials that have been manufactured and stored as precision strip metal on coils. Metal suppliers offer a flattening and cutting to length service. This is especially useful for metals that are prone to high degrees of coil set. The process is one of back rolling to eliminate the curvature caused by coil set and then cutting the strip to lengths, typically 500mm long. The cut sheets are then palletised as flat sheets ready for processing. As the material does not have to be recoiled the flatness is maintained. This type of supply is available for all types and gauges of metal, but is subject to minimum processing quantities and therefore not suitable for very small quantities.

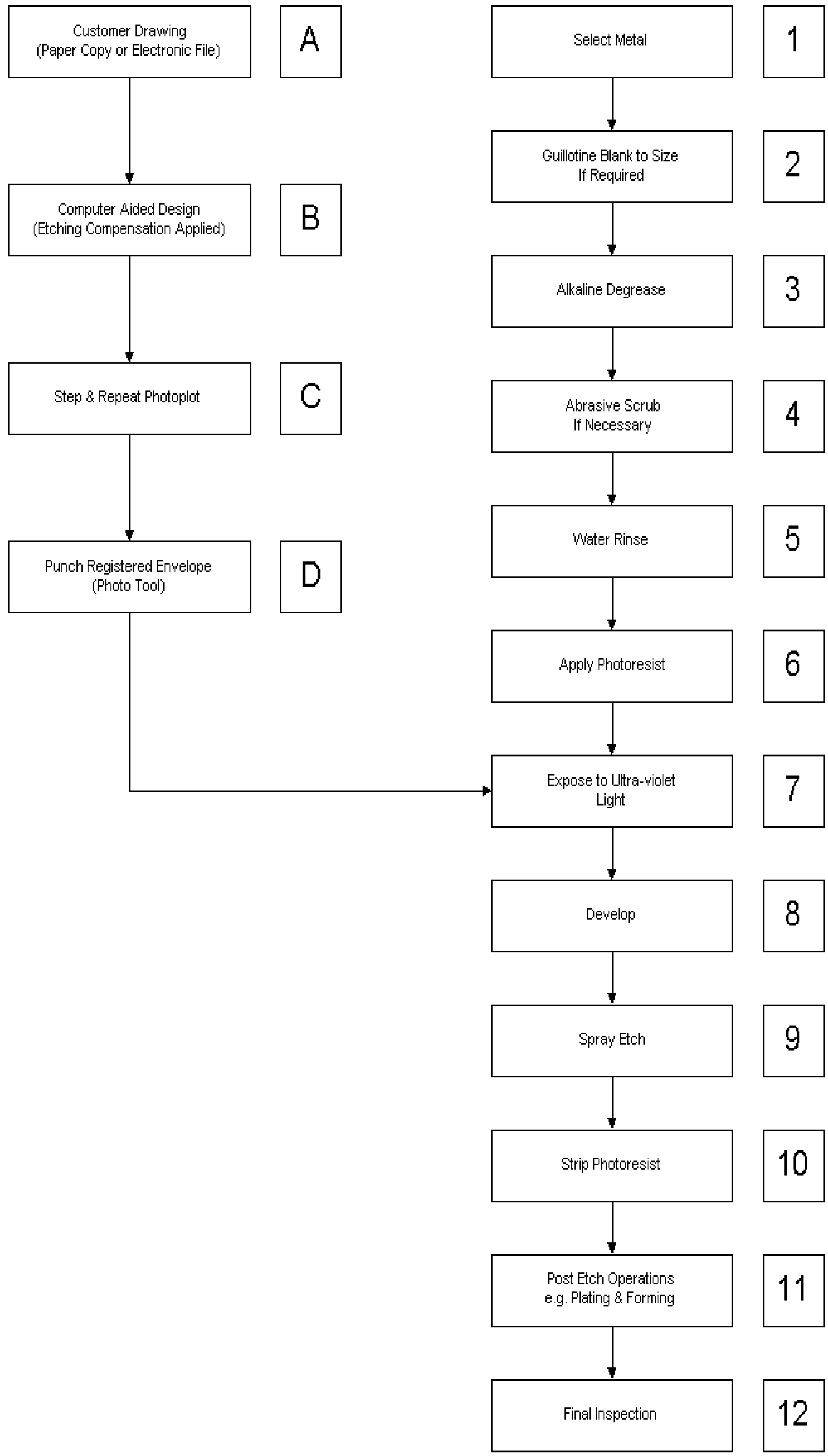
It is extremely important that at the rolling mill, and during the flattening operation, that the surface of the metal is kept free from machinery lubrication especially silicone oils or grease. As this can contaminate the surface of the material and ingress into the voids between the individual grains, causing processing problems at the cleaning stage (refer to metal preparation).
It is common place within the industry for a wide range of stock materials to be held. All metals must be fully certificated and traceable at the time of reaching Goods In. This procedure ensures there is no delay in confirming the stock held conforms to the customers' specification.

MECHANICAL PROPERTIES

Mechanical properties of the metal are unimportant to the photo etch process. Sheets need to be flat and free from surface contamination (refer to specific requirement for the process). Temper of the metal does not affect the etching process but may affect any post etch operations. Also the etching process itself does not affect in any way the temper of the material. Fully annealed material stays fully annealed and fully hardened material is easily processed without altering the hardness.

The etching process acts on the material at a grain structure level (refer to component manufacture), therefore metals with an even grain structure, yield better results than those without. Grain direction of the stock material is not critical. Orientation of grain direction to component can be adjusted at the printing stage (refer to production of phototools).

Process Flow Chart



PHOTOTOOLING

In order to transfer the image of the required cutting lines onto the photoresist some form of masking has to be produced. This mask consists of a sheet of clear acetate with black lines where the photoresist is to be masked from the ultra violet source (refer to image creation). As the metal is covered and etched on both faces 2 films are required, these films are known as a phototool or P.R.E (punched register envelope).

PHOTOTOOL PRODUCTION (Cut and Peel)

In the early days of Photo Chemical Machining the phototools were produced by a cut and peel method, this involved cutting the component profile from a material that consisted of a sheet of acetate covered by a plastic film. One such material was known as Rubylith. The profile of the flat component, including any etching compensation factors, was cut through the sheet of plastic but not through the acetate. A further profile was cut to allow for the thickness or width of the cut line required. The cuts were made with a digitally controlled pantograph, which in itself gave very accurate results. Where possible the image was cut at 10 times full size or at an absolute minimum 5 times full size. After all the cutting had been undertaken the unwanted parts of the plastic was peeled away and discarded. At this stage the cut and peeled image was photographically reduced in scale to 1:1 and stepped and repeated as many times as practically possible onto photographic film, the resulting film was ready for use as a phototool.

With the introduction of Computer Aided Design and the ability to transfer drawing electronically this technology has now become obsolete within the PCM industry.

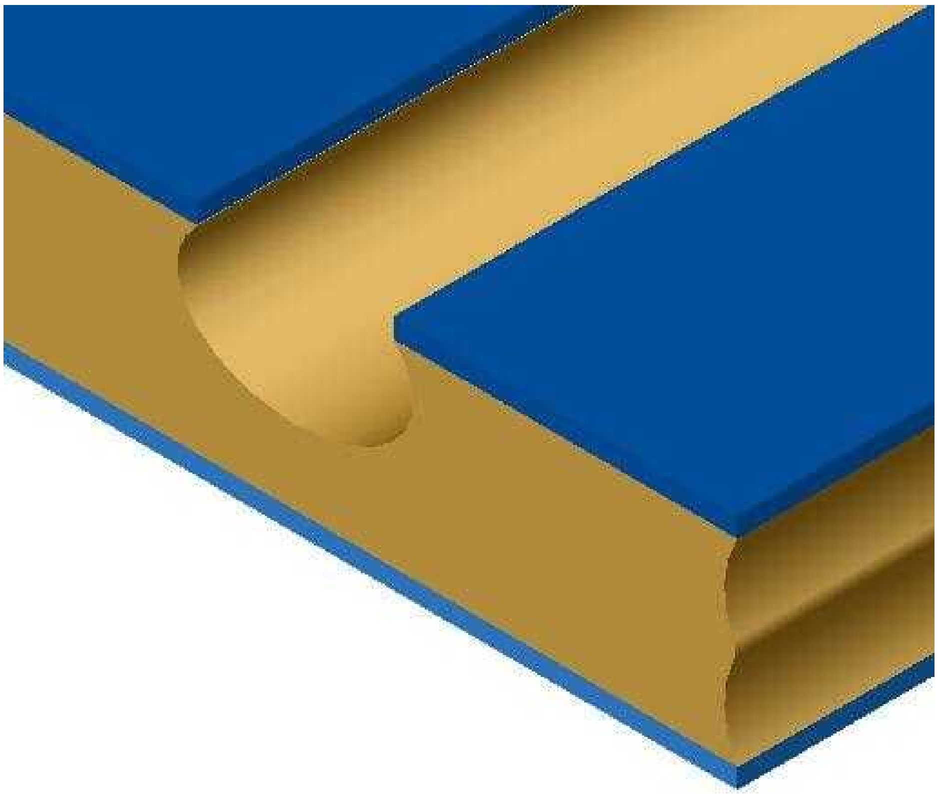
PRODUCTION OF PHOTOTOOLS (Light Plotted)

Modern technology now allows an image of the profile of the flat component to be transferred directly to the photographic film that is to be used as the phototool by way of a light pen plotter. These plotters operate in exactly the same way as a pen and paper plotter except that photographic film is substituted for paper and light for ink.

Upon receipt of a drawing a 2D CAD image is created, which may involve calculating bend allowances and inclusion of half etch detail where required. To allow for the etching process an etching compensation factor has to be added. This involves drawing the outside profile larger than the finished component size and holes and slots smaller. The amount of adjustment is directly proportional to the thickness of the metal being processed.

In general terms, for metal gauges including and above 0.3mm the width of the cutting line should be equal to the thickness of material being processed. The etch rate, or processing speed, is proportional to the width of cutting lines. Consequently where the component profile allows, metal gauges below 0.3mm should be processed using phototools with cutting lines plotted at 0.3mm wide. After the adjusted profile has been drawn the image is repeated to gain maximum utilisation of the sheet area, taking into consideration the metal grain direction if applicable. It is at this stage that tabs to hold the component into the sheet are drawn on the profile if required, together with identification of the tool. Because 2 films are necessary to transfer the required image, it is possible to vary the detail of each film. Any cut line or text detail present on one film only will be duplicated on just one face of the metal, this detail will only be etched from one side, penetration will be at approximately 60% by the time detail on both faces of the film have pierced the sheets.

ILLUSTRATION OF HALF-ETCH DETAIL



This characteristic can be very useful as half etch is used for fold lines and identification marks.

Tools are always plotted so that in use the emulsion side of the film will be in direct contact with the photoresist; failure to adhere to this orientation will result in a diffused line. If the phototool has no half etched detail, then the second film can be produced by contacting the first developed film with an unexposed negative type held tightly together with a vacuum and exposed to a light source. This process is undertaken after film registration holes have been punched to create a perfect top to bottom alignment or registration. Tools with half etched detail have to be plotted on an individual basis. Registration of the images is then achieved optically with the aid of magnification but is easily achieved to an accuracy of 15μm.

GENERAL CORE AND DESIGN OF PHOTOTOOLS

The life cycle of a phototool is approximately 400 print cycles. For volume production runs it is often prudent to produce a negative master film from which a positive film can be quickly produced by the contact method.
It is advisable where the design of a component allows, to avoid the manufacture of a tool which produces large areas of photoresist removal. Large exposed areas of metal

have a faster rate of etch than cut lines and can cause tolerancing problems coupled with a faster contamination of the etching chemistry.

METAL PREPARATION

CLEANING

The selected metal has to be cleaned prior to having the photoresist applied (refer to the process flowchart). The cleaning operation is necessary to remove the oil, grease or any substance from the surface of the metal that would prevent good adhesion of the photoresist.

There are 2 methods of cleaning, mechanical and chemical. Mechanical cleaning usually involves some form of scrubbing in conjunction with a suitable mild de-greasing solution. This method gives a good result but is not practical for very thin gauge metals. For example 0.013mm stainless steel or 0.050mm copper is almost impossible to scrub without causing mechanical damage.

Experiments have been conducted with ultrasonic cleaning; it has proved to be a slow process that is probably not best suited for this type of application.

Chemical cleaning is a mild pickling process. The sheets of raw material are suspended in a degreasing solution that typically consists of 30% phosphoric acid plus other degreasing agents as added by the solution manufacturer. The proprietary cleaner is diluted to a 10% solution but this is of course dependent on the manufacturers recommendations. Some heating of the solution is beneficial. The temperature is not critical, typically 45 degrees centigrade gives a good clean. After soaking for approximately 10 minutes the sheets are given a clean water rinse. The next process is dependant on the type of photoresist to be applied (refer to Laminating).

PROTECTIVE COATINGS (Photoresist)

PHOTORESIST TYPES

There are 4 types of photoresist - wet film positive, wet film negative, dry film positive and dry film negative.

Negative film requires exposure to UV light to harden the film whereas positive film is softened when exposed to UV light. Positive film is commonly used in the printed circuit industry but offers no advantage to the component manufacturing industry.

WET FILM NEGATIVE

This film is applied to the surface of the metal in liquid form.

Advantages: Wet film has lower cost than dry film and if applied correctly allows the use of finer etched lines. Better resolution can be achieved. The edges of the metal are coated including any slots or holes.

Disadvantages: The surface of the metal has to be cleaned to an extremely high standard. The work area where the resist is applied has to be dust free, the minimum requirement for successful application being a positive pressure room using filtered air, but ideally a clean room with all the associated disadvantages of such a set up in a manufacturing environment.

Applying the resist is a dipping process and it is not easy to achieve a constant thickness of film, the viscosity of the liquid being critical. It is common for the thickness of the resist to get progressively thicker from the top to the bottom of the sheet as it is left to drain. (The optimum constant thickness for wet film resist is 5µm). After draining the resist has to be baked which is both costly and time consuming. The resist has to be removed or stripped from the finished components with a solvent based cleaner, which does cause environmental issues, especially the control of noxious solvent fumes.

WET FILM POSITIVE

This type features the same advantages and disadvantages as wet film negative, but has reversed developing characteristics.

DRY FILM NEGATIVE

Dry film is available in a range of thicknesses from 25µm to 125µm supplied in rolls of various widths. The resist is protected on the roll by a polymer film which does not have to be removed until the sheet is developed (refer to printing and developing). This polymer film gives protection to the resist in it's soft, pre-exposed state. The film is applied to the metal sheets by a combination of heat and pressure by way of heated rollers. The speed and temperature of the rollers can be adjusted to suit the metal type and thicknesses. The most common resist thickness for component manufacture is 38µm but 25µm is used to achieve finer etch lines when required. Film with a thickness above 38µm is rarely used as it has been found that a double layer of film withstands the hostile environment of the etching process better than a single thick film.

Advantages: The application of the film is not so critical to dust; therefore no special air filtering requirements are needed. If the sheets are laminated whilst still wet from the cleaning rinse, the laminating rollers remove the water along with any dust on the metal surface. A constant thickness of film is assured. The polymer coating on the film helps protect the resist from damage during printing. Dry film is not susceptible to pin holing. It is possible to tent over holes, slots and half etch detail (refer to component manufacture).

Dry film laminating is a faster process than wet. If an aqueous based resist is used then the stripping process requires no solvent-based chemicals, and it can be stripped with a caustic soda solution.

Disadvantages: The material costs are much higher than with wet film. It is not possible to coat the edges of holes; slots or the metal sheet with resist.
A range of widths and thicknesses has to be stocked to allow efficient use of materials.

It is difficult to apply dry film to thicker materials above 2mm unless the metal is pre-heated prior to lamination. Thicker metals often haven to be double laminated to prevent resist lift during the etching process (refer to component manufacture).

DRY FILM POSITIVE

This type features the same advantages and disadvantages as dry film negative but has reversed printing and developing characteristics (refer to photoresist types).

LAMINATING

Laminating (the application of the photoresist) is carried out immediately after the metal has been cleaned. The process is dependent upon the type of photoresist being used. For wet film resist the metal sheets are dipped into the liquid resist and allowed to drain until an even thickness of coating is achieved. The coated sheets are then baked in an oven to cure the film prior to printing and developing.

For dry film resist the sheets can be fed through the laminating rollers whilst they are still wet. It is essential that the speed of the rollers is proportional to the metal thickness being laminated. The polymer film is left on the surface of the photoresist until the printing operation has been undertaken unless the sheets are to be double laminated, in which case the polymer film is removed and the sheets are immediately passed through the laminating process for a second time. Both types of film now have to be protected from uncontrolled ultra violet light until the developing process has been undertaken.

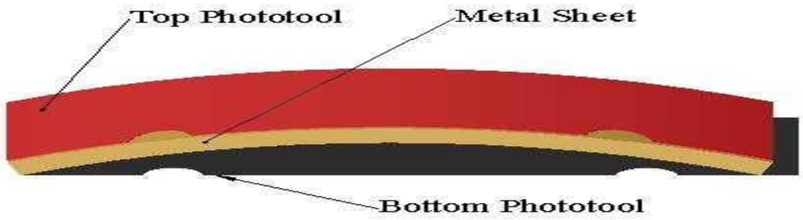
IMAGE CREATION

PRINTING & DEVELOPING

The printing of the metal sheet is carried out by using a punch registered envelope which consists of 2 photographic films (refer to Production of Phototools) and an ultra violet light source. The object of the printing and developing process is to produce sheets that have cut lines i.e. bare metal areas on both faces where the etchant is required to act. Where the metal is to be unaffected by the process it remains covered in photoresist film.

Registration of the films to each other is critical to achieve component accuracy as is flatness of raw material (refer to raw materials). A bowed sheet will cause progressive misalignment or out of registration image.

ILLUSTRATION OF MIS-REGISTRATION



The film registration is achieved at the phototool production stage. Providing any curvature is removed during the printing operation, registration is not an issue. This curvature is removed by either mechanical pressure (by sandwiching the metal and films between 2 sheets of glass) or by vacuum. (A flexible top sheet pulling down on a rigid glass lower sheet.

Once the phototools are in contact with the surface of the photoresist the whole assembly is exposed to an ultra violet light source. The exposure time is dependent upon the thickness of the masking lines present on the phototool.

DEVELOPING

Developing is the term used for the chemical removal of the unplasticised areas of the photoresist. The printed sheets are passed through the developing machine on a conveyor, where the unexposed areas of resist are removed with a sodium carbonate based solution. It is during the developing stage the bare metal cutting lines are produced. The developing operation is the final task before the sheets are subjected to the photo chemical machining process. If dry film resist is used the polymer film is removed prior to developing. Once developed the prepared sheets are no longer sensitive to ultra violet light and can be freely removed from the controlled light spectrum of the print room area. Special care has to be taken when very fine lines (less than 0.15mm wide) are present on the phototool. It is often necessary to double develop that is passing the exposed sheet through the developer twice. A small piece of undeveloped photoresist present on the cut line will always result in an unsatisfactory etch quality of that specific component. Even the smallest piece of photoresist present on a cutting line will prevent the etchant attacking that area. If for processing reasons the material sheets have to be double laminated, then double developing is always a necessity.

COMPONENT MANUFACTURE

THE PHOTO CHEMICAL MACHINING PROCESS FOR COMPONENT MANUFACTURE

One of the key strengths of the etching process is that the chemistry is unaware of the hardness (or type) of material that it is etching through. This is due to the way that etchant chemistry breaks down the materials grain structure, which only changes slightly with temper (refer to materials section). The component etching process was originally developed in the 1940s to manufacture parts from materials too hard to stamp or machine.

Etching also has no detrimental effect on the properties of the material surrounding the etched areas. Concerns of localised annealing or embrittlement do not occur during the process. This gives etching the advantage of being able to create component shapes in any hardness of material from annealed to spring hard. The ranges of material types/thickness regularly etched in commercial production are listed in the Raw Materials section.

EQUIPMENT

The modern spray-etching machine is almost universally used in production photo chemical machining. The workpiece, or sheet, travels along a horizontal conveyor consisting of rubber wheels on GRP rods which carries it through a rigid PVC chamber, where it is vigorously sprayed with hot etchant from batteries of nozzles above and below the track. The most productive etch rate is achieved when the etchant is sprayed perpendicular to the workpiece. This ensures that as the cut moves through the workpiece the main pressure is directed to the base of the cut, therefore only attacking the side walls by diffusion.

ETCH FACTOR

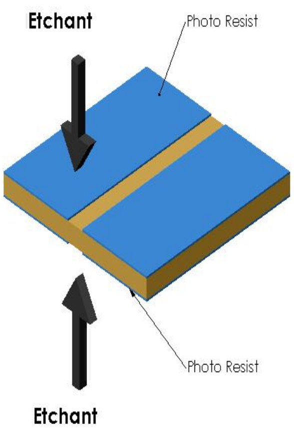
The ratio of etch depth to undercut is called etch factor and is determined by the process chemistry and the spray pressure and direction of its application. The differential etch rates at the floor and sides of the spray etch cavity are responsible for the characteristic profile of the finished edge. The profile develops as if an ellipse of increasing size were sinking into the metal surface. As etchant is applied under pressure then the point that receives the greatest impact of that pressure will etch quicker. This is always intended to be the base of the cut, therefore the cut will travel down (and up) through the material quicker than along the horizontal

TYPICAL ETCHANT DIFFUSION

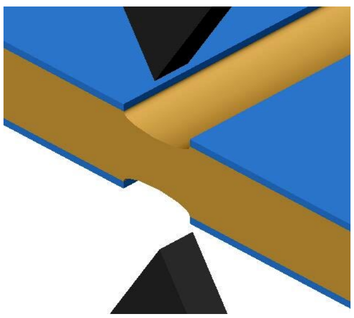
EDGE PROFILE

The cutting action of the chemicals does create a characteristic edge profile referred to as a bi-cuspic edge. This has the appearance of a seagull in flight. This is the result of simultaneous etching from both sides leaving a witness at the point of breakthrough. As the etching proceeds the bicuspid edge retreats at a decreasing rate. The nearer to the horizontal the surface the faster it etches, therefore the protruding cusp is reduced faster than the nearly vertical sidewalls.

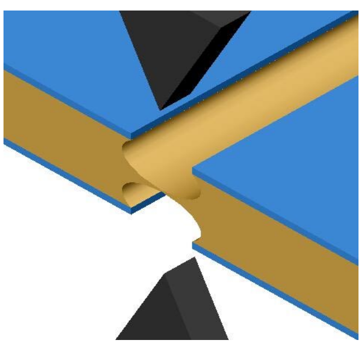
As etching continues the bicuspid edge becomes progressively straighter and almost vertical. Further etchback would result in overetching and a concave edge protruding into the materials section by as much as 1/5th of the materials thickness. The phototool will have been sized to achieve nominal dimension at straight wall (refer to phototool production). The rate of etch slows as the edge profile becomes vertical. Consequently if the product comes to size midway through a machine pass it will not be overetched and therefore undersize by the end of the pass.



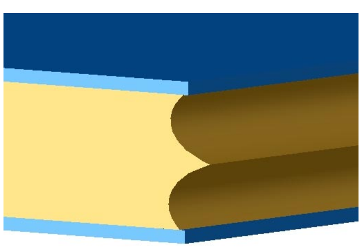
PRE ETCH



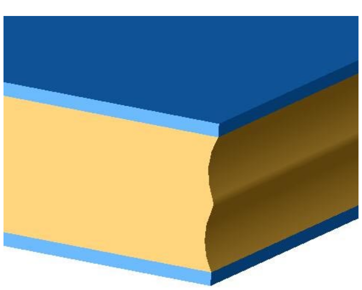
EARLY STAGE ETCH



PRE BREAKOUT PROFILE (BI-CUSPIC EDGE)



INITIAL BREAKOUT PROFILE



FINISHED PROFILE

CHEMISTRY

The majority of photo chemical machining is carried out with aqueous solutions of ferric chloride. It is inexpensive, readily available, versatile in that it attacks the majority of commonly used engineering metals and alloys, and it has a high capacity for dissolving those metals. Environmentally it is attractive as it is of low toxicity and relatively easy to filter, replenish and recycle. Also it is used extensively in water treatment processes. Ferric nitrate is used for the etching of non-standard materials such as molybdenum and silver.

Ferric chloride is a black solid that dissolves in water to give a clear, red brown, astringent solution. Ferric is supplied in 2 principle grades, or purchased in one condition and treated on site to suit application.

Due to the importance of chemistry in the etching process it is common to have onsite technical support in the form of laboratory facilities plus chemistry technicians. This allows for regular monitoring and adjustment of the condition of the production chemistry. Regular monitoring is essential, as the properties of the etchant chemistry will alter constantly as they react to the elements transferred into solution from the materials etched. The elements added to the chemistry can increase or decrease the effective strength of the etchant. A consistent etch rate is important for production rate, etch quality and dimensional stability of the processed components, particularly over a large batch.

RATE OF ETCH/DIMENSIONAL CONTROL

The depth of cut achieved during each pass through the etching machines depends on the length of the machine, the speed of the conveyers and the pressure and the strength of the etchant. The slower the conveyers the longer the workpiece is in the etching chambers. Therefore the greater time exposed to the etchant and so more material removed. The product cycle time measured in total number of passes and speed of each pass will be dependent primarily on material thickness. Slow passes, used at the start of etching with possibly quicker passes towards the end to finely control the rate of etch, will achieve dimensional tolerance.

The alloys contained within the material will also effect the etch rate sometimes quite considerably. Material hardness can also have a marginal affect on the etching rate. The main alloys contained within materials that can reduce etch rate when operating with Ferric Chloride are: Carbon, Cobalt, Titanium and Silicon. However most metals contain a only small percentage of these elements and therefore this does not often create difficulties.

Due to the demand for mild and spring steel components in general manufacturing the high quantities of carbon within these materials creates a problem, as it is very effective at resisting the cutting attack of ferric chloride. Once it is released from the material into solution it settles back onto the material blocking further attack by the etchant chemistry. This problem is overcome by effective filtering of carbon from the solution avoiding the problem of redeposition. Another solution is to scrub the sheets after every pass through the machines to clean the cutting line area of carbon deposits.

MULTI STAGE ETCHING

A key attribute of photo chemical machining is its flexibility as demonstrated during a multi stage etching procedure which relies upon repetition of elements of the manufacturing process. For example: Take a component design requiring partial thickness reduction in a small area to say 3/4 of material thickness (t). Half etching from one side during the main profile cut would result in a finish thickness of 1/2 (t) in that area, which would be too deep. The only way to achieve a 3/4 (t) would be to selectively etch the area requiring the thickness reduction initially.

The sheet of material would be prepared, laminated and printed with a single sided phototool exposing the area to be surfaced etched only (the component profile would remain undeveloped at this stage). The sheet would be etched until the correct thickness had been achieved in the exposed area. Once complete, the sheet is stripped of resist, cleaned and prepared for re-laminating and printing.

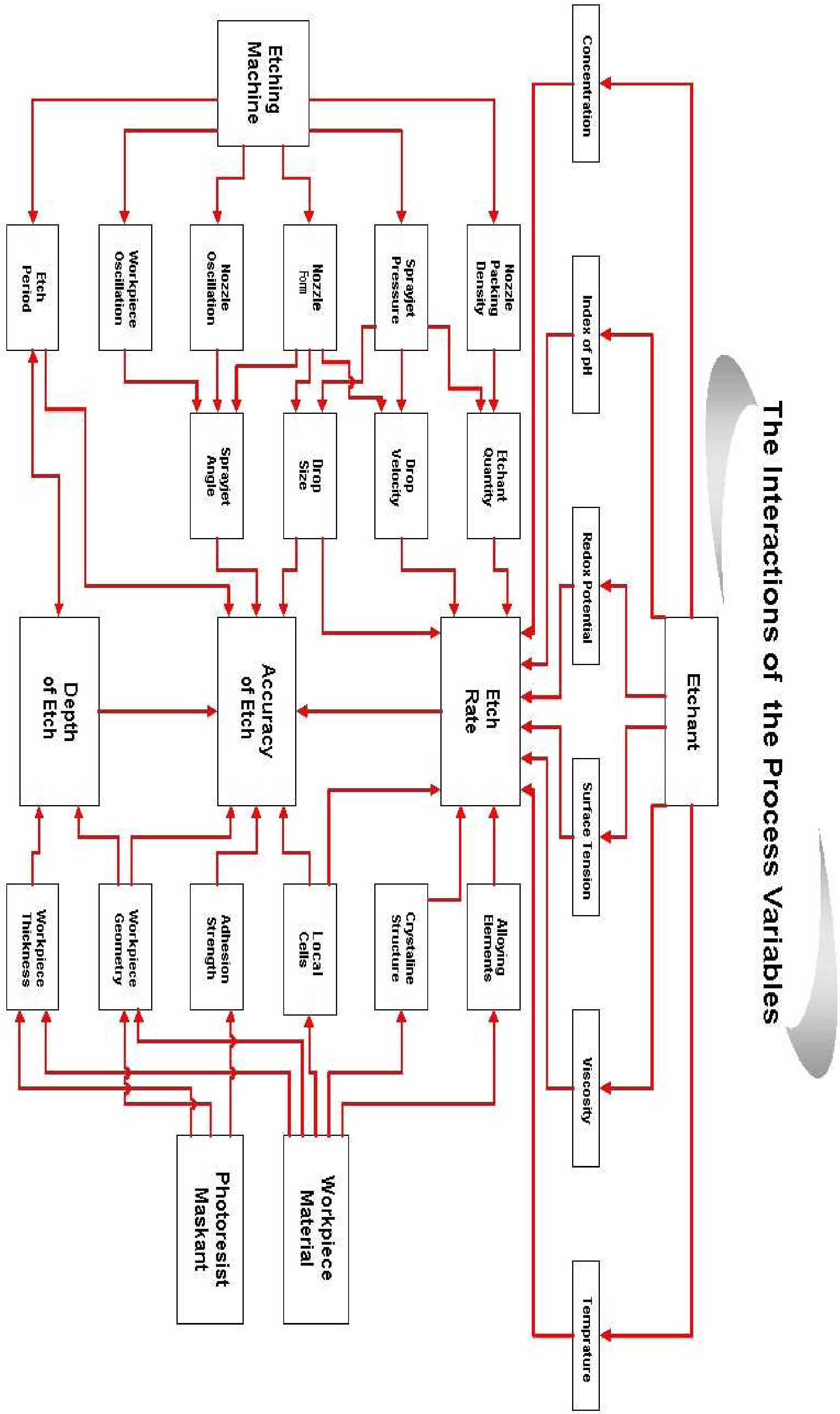
This time a double-sided phototool is used which includes the component profile and any through feature details. The previously surface etched area is not developed this time. The sheet is then etched until the components are to finished size, the surface etched area is not attacked by the etchant during this second stage due to a protective tent of new photoresist. Once the component has completed its second etching stage the resist is stripped off as normal and the finished part, complete with its accurately thinned area is ready for any further manufacturing stage.

REMOVAL OF RESIST (STRIPPING)

Photoresist can only be removed by chemical means to avoid damage to the etched components. Different chemicals are utilised to strip different resist formulations. However the photoresist in most common usage is aqueous dry film that can be effectively stripped using a mild caustic soda solution.

The stripper solution is applied onto sheets of components in a conveyorised machine, which also has rinsing and drying chambers. Alternatively if the components are loose, then they will be hand stripped in mesh baskets in dip tanks.

Once stripped, the components are dimensionally inspected and ready for any appropriate secondary operations, such as plating forming, machining, assembly etc. or shipment to the customer if no additional processes are required.

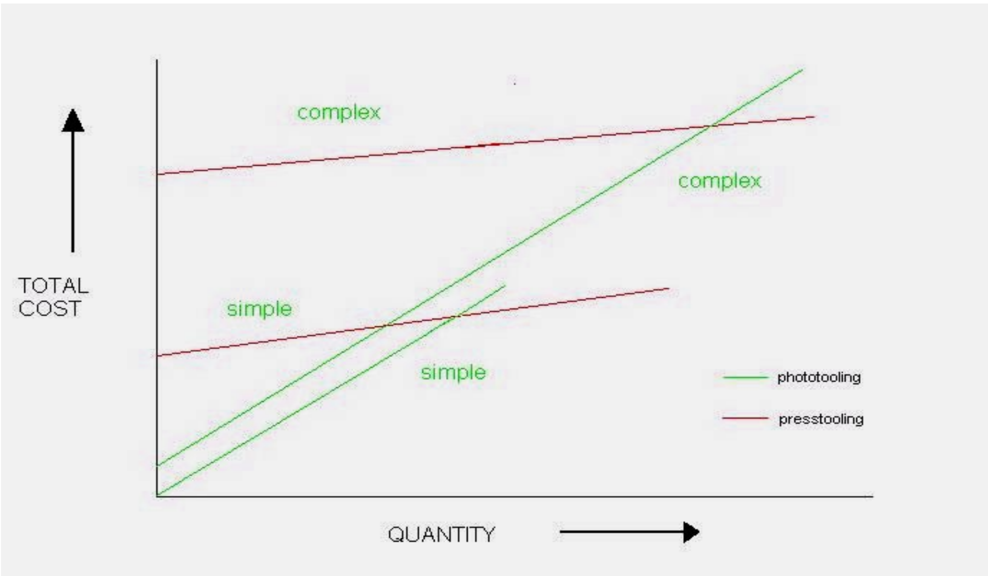

The Interactions of the Process Variables
Etchant
Concentration
Index of pH
Redox Potential
Surface Tension
Viscosity
Temprature
Etching Machine
Nozzle Packing Density
Sprayjet Pressure
Nozzle Form
Nozzle Oscillation
Workpiece Oscillation
Etch Period
Etchant Quantity
Drop Velocity
Drop Size
Sprayjet Angle
Etch Rate
Accuracy of Etch
Depth of Etch
Alloying Elements
Crystaline Structure
Local Cells
Adhesion Strength
Workpiece Geometry
Workpiece Thickness
Workpiece Material
Photoresist Maskant

ECONOMOMICS OF THE PHOTO CHEMICAL MACHING PROCESS (PCM)

PCM is specified where the required component material is: too hard, too soft, too thin or too complex for conventional metalworking techniques and where freedom from burrs and/or stress is paramount. If the complexity of the profile makes press tooling expensive or impractical or if the quantity of parts required is too small to justify the cost of press tooling.

The unit cost of a photo chemically machined part is higher than that of a pressed product because consumables and the overheads of this high technology manufacturing operation are relatively high, (e.g. you double the cost of the raw material when you coat it in resist). However, the tooling costs are low typically £80 - £120. But most importantly the lead-time is measured in hours.

A press shop can produce parts at a high rate and cheaply but the tooling cost is high and the lead-time is weeks, if not months. A graph and calculation showing a method of arriving at a break-even quantity for units of production (Q) is shown below.



$$Q = \frac{D - A}{Pe - Ps}$$

Q = number of parts
D = press tool cost
A = phototool cost
Pe = etched part cost
Ps = pressed part cost

However the decision upon method of production should not be made solely on this basis since one or more post blanking operations may be avoided by the use of the etching process. Take the example of full hard spring steel products. Traditional methods would require the stamping of the components from annealed material then hardening by heat treatment. This carries with it a risk of distortion and burrs, which may require either a design compromise or additional finishing operations. If the components were to be photo chemically machined, they could be manufactured from full hard material thereby avoiding any risk of distortion, burrs and subsequent finishing costs.

PCM is not only capable of profiling the blank, but simultaneously produces at no extra cost other details such as holes, slots, fold lines, grooves rebates and surface engraved part numbers which would otherwise be additional operations. When the same supplier combines the PCM process with press shop and machining facilities, then the customer can have the best of both worlds. Sourcing etched formed components from one supplier can further reduce total cost of purchase, production time and vendor base. These cost savings should be taken into account when deciding which production method to specify.

This concept is particularly beneficial where a customer orders prototype parts that are to be photo chemically machined. Once the design is approved, the customer then has the option to stay with the PCM company for the production requirements, utilising volume etch production techniques and multi stage blank forming. Alternatively if the volume is high it may be appropriate to stay with the PCM company for supply continuity in the early stages of production demand while the press tooling is manufactured and approved.

ADVANTAGES OF PHOTO CHEMICAL MACHINING

Half etched fold or bend lines
Multi level depth etching
Low cost tooling
Lead-times in hours/days not weeks/months
Any material temper
Virtually every metal type
Stress and burr free manufacture
No additional costs for complex shapes
Interfaces easily with other manufacturing techniques
No impact on component material properties
Simultaneous part marking/corporate ident
Low and high quantities
Economic manufacturing costs

ENVIRONMENTAL CONSIDERATIONS

Every manufacturing process has an environmental impact. The goal of any responsible manufacturing company must be to minimise the impact of their operations. The development and implementation of a company wide environmental policy is vital in the education of workforce and suppliers. Qualitetch have such a policy that is subscribed to by all company employees as a living policy, not a publicity statement.

ENVIRONMENTAL POLICY

Qualitetch Components Ltd applies the following environmental principals to all it's activities:

We are committed to continual improvement in our environmental performance, paying special attention to the following issues:

1. Effective management of our emissions to air, water and land, seeking their reduction where practicable.

2. Compliance with relevant legislation covering any of our operations.

3. Ensure our processes and operations prevent pollution.

4. Efficient use of energy.

5. Minimisation of our consumption of natural resources.

6. Effective management and minimisation of our waste streams.

We are committed to working in accordance with and maintaining the environmental management systems standard EN ISO 14001.

We are committed to setting environmental objectives and targets and monitoring and reviewing of our environmental performance against these objectives and targets.

We will encourage understanding of our environmental policy and objectives by our suppliers, customers and contractors.

We will make our staff aware of the environmental implications of their work as it affects our customers and ourselves.

We are committed to giving our employees and contractors all necessary instruction to enable them to comply with our environmental policy.

We are committed to providing the resources to enable us to implement our environmental policy.