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AEROSPACE RECOMMENDED PRACTICE

Submitted for recognition as an American National Standard

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REV. A

THE CHEMICAL MILLING PROCESS

1. PURPOSE:

1.1 This recommended practice provides recommendations concerning the chemical milling of aluminum, magnesium, and titanium alloys, and specialty alloys.

1.2 The detailed recommendations are based on practical engineering and production experience that will enable industry to make proper use of the chemical milling process.

1.3 Safety - Hazardous Materials: While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. GENERAL: Chemical milling is a process used for controlled dissolution of metals in order to obtain weight reduction and specific design configurations. The amount of metal removed is a function of the material being etched, the etchant composition and temperature, and the time of immersion in the etchant solution.

2.1 Application of Chemical Milling Process: This process can be used in the following ways:

2.1.1 Remove metal from the surface of formed or irregular shaped parts, such as forgings, castings, extrusions, or formed wrought stock. Metal may be removed from the entire surface of the part or from selected areas.

2.1.2 Reduce web thicknesses below practical machining, forging, casting, or forming limits.

2.1.3 Taper sheets and preformed shapes.

2.1.4 Produce stepped webs, resulting in the consolidation of several details into one integral piece.

2.1.5 Remove metal from the surface of tough, hard-to-machine alloys.

2.2 Advantages of Chemical Milling Process: The advantages of this process are as follows:

2.2.1 A part may be chemically milled on both sides simultaneously. In so doing, the part is processed twice as fast and warpage, which might result from the release of "locked in" stresses, is minimized.

2.2.2 Production capacity is increased because many parts can be chemically milled at one time. This can be done by chemically milling a large piece before cutting out the parts or by milling many separate pieces in the tank at one time.

2.2.3 Close tolerances may be held when chemically milling.

2.2.4 There are many ways to save weight by using this process. Extrusions, forgings, castings, formed sections, and deep drawn parts may be lightened considerably. Raw stock, such as sheet or bar, which would normally be heavier because of the limitations due to standard sizes or minimum thickness restrictions required for forming, forging, or casting may also be lightened considerably. Using this process, parts may be produced with very thin web sections without fear of excessive warpage or distortion by observing the proper relationship between pocket size and web thickness.

2.2.5 Tapering of sheets, extrusions, or formed sections may be readily accomplished by using this process. Various tapers may be made on one or both sides of a part.

2.2.6 The design of sandwich construction parts can be improved by leaving heavy bands or stiffeners (integral with one or both skins) at attachment points.

2.2.7 Parts may be formed and heat treated prior to chemical milling. Since forming is easier prior to the machining operation, less expensive forming dies are required and costly "check and straighten" work is largely eliminated. Warpage resulting from heat treating is also minimized.

2.2.8 The process permits the design of lighter-weight, integrally-stiffened parts which are simplified by the elimination of riveting, welding (seam, spot, and fusion), or metal bonding.

2.2.9 Parts manufactured by this process normally require no subsequent sanding or polishing of the milled surface.

2.2.10 The surface finish of many castings can be improved by chemical milling.

2.2.11 Thin parts may be blanked out using special techniques incorporating the use of photosensitive masks and spray etching equipment.

2.2.12 Machine practicality or conventional machining methods need not limit the designer or manufacturer of chemical milled parts.

2.3 Limitations of Chemical Milling Process: The limitations of this process are as follows:

2.3.1 Fillet radii are determined by factors such as depth of cut, alloy, etchant, and maskant and are approximately equal to the depth of cut. Inside corners take a spherical shape; outside corners remain sharp.

2.3.2 Aluminum alloy castings are normally difficult to chemical mill due to the porosity and inhomogeneity of the cast material. Such castings may be chemical milled where neither smooth surfaces nor high strengths are required.

2.3.3 Welded parts must be considered individually because chemical milling over a welded area often results in pits and uneven etching. Many welded materials can be satisfactorily chemical milled; however, individual tests should be performed to determine the advisability of chemically milling a particular part. Parts may be chemical milled by masking the welded area.

2.3.4 Surface irregularities, such as dents and scratches, are reproduced in the chemical milled surface of aluminum alloys. Surface dents and scratches in magnesium alloys tend to wash out or disappear as a result of chemical milling. Selective masking of scratches and dents can be used to produce good parts.

2.3.5 Surface waviness and thickness variations are reproduced but not enlarged.

2.3.6 Normally, cuts in excess of 0.500 inch (12.70 mm) deep are not recommended.

2.3.7 Holes, deep and narrow cuts, narrow lands, and sharp, steep tapers should not be attempted.

2.3.8 No one etchant can be used on all alloys. Caution should be exercised in selection of the etchant for the alloy being chemical milled.

3. RECOMMENDATIONS:

3.1 Design Considerations:

3.1.1 Depth of Cut: Although cuts up to 2.0 inches (51 mm) deep have been made in plate, the following limitations may be used as a guide:

	Maximum Depth Per Surface	
	Inch	Millimetres
Sheet and Plate	0.500	12.70
Extrusion	0.150	3.81
Forging	0.250	6.35

3.1.2 Depth of Cut Tolerance:

3.1.2.1 Because the etchant solutions used in the chemical milling process reproduce the thickness variations of the original raw stock, the question of expected process tolerances is indeed complex. When forging or machining operations precede chemical milling, either the final tolerances must be enlarged to allow for the thickness variations introduced by these operations or these variations must be removed.

3.1.2.2 The process tolerances can be improved by using premium or close tolerance stock, by pregrinding or chemical sizing stock to a close tolerance, by segregating incoming stock according to actual thickness by individually handling during the etching cycle or, where possible, by using narrower widths of standard sheet which are controlled to a closer tolerance by the producing mill.

3.1.2.3 A reasonable production tolerance for chemical milling is ±0.002 inch (±0.05 mm). To this must be added the actual raw stock tolerance prior to chemical milling. With the above comments in mind, the tolerances shown in Figure 1 are recommended as a guide for production chemical milling.

3.1.3 Lateral Tolerances: For cuts up to 0.250 inch (6.35 mm) deep, a lateral tolerance of ±0.030 inch (0.76 mm) is normal as shown in Figure 2. This tolerance can be reduced considerably, as also shown, with maximum effort.

3.1.4 Minimum Land Width: The minimum land width should be twice the depth of cut but not less than 0.125 inch (3.18 mm). It need not be greater than 1.0 inch (25 mm). Narrower lands are possible but more expensive to achieve.

3.1.5 Minimum Width of Cut: The minimum width of cut should be twice the depth of cut plus 0.060 inch (1.52 mm) for cuts up to 0.125 inch (3.18 mm) deep and twice the depth of cut plus 0.125 inch (3.18 mm) for cuts over 0.125 inch (3.18 mm) deep.

3.1.6 Cuts on Opposite Sides: Cuts on opposite sides of the metals should not be directly opposite one another because of the heat transfer problem. The recommended minimum distance between cuts on opposite sides for normal production work is 0.250 inch (6.35 mm).

3.1.7 Tapers: Tapers greater than 0.100 inch per lineal foot (8.33 mm/m) are not recommended for aluminum. Larger gradual tapers are recommended for other metals.

3.1.8 Grain Direction: Aluminum parts should be chemical milled in such a way that the length of the cut will be parallel to the grain.

3.1.9 Surface Finish: The surface finish of chemical milled parts is determined by the initial surface finish, alloy, heat treat condition, depth of cut, and etchant used. In general, good quality stock free from scratches, pits, and other damage should be specified for chemical milled parts. The following surface finishes can be expected:

Aluminum	-	53 to 142 RHR	(1.35 to 3.62 µm)
Magnesium	-	27 to 63 RHR	(0.69 to 1.60 µm)
Steel	-	27 to 223 RHR	(0.69 to 5.68 µm)
Titanium	-	13 to 45 RHR	(0.33 to 1.15 µm)

3.1.10 Forming and Heat Treating: Parts should be formed and, when necessary, heat treated prior to chemical milling.

3.1.11 Trim Area: Whenever possible, chemical milled parts should be designed with trim area. Trim area is excess material surrounding the actual part. The excess material is trimmed off after chemical milling. When no trim area is provided, much time and money is spent in protecting the edge of the part.

3.2 Tooling Considerations:

3.2.1 Template Materials: The two most popular template materials are aluminum sheet and glass laminates. Aluminum templates are recommended for flat or slightly curved surfaces. Glass laminates are recommended when contoured or irregular shapes are to be scribed.

3.2.2 Template Design: Whenever possible, templates should be designed with a minimum of stiffeners across scribe lines so that a knife slip, during the scribing operation, whould affect only the area of strippable mask.

3.2.3 Undercut Ratio: Inasmuch as the process etchant solution dissolves metal not only in a direction perpendicular to the exposed surface but also undercuts the mask, this undercut ratio or etch factor must be known for each alloy and designed into the template.

3.2.4 Color Coding: On chemical milling templates that have more than one level of cut, a color code designating the sequence of mask removal is recommended. In addition, the depth of cut and final thickness for each level should be permanently marked on the tool.

3.3 Production Considerations:

3.3.1 Cleaning:

3.3.1.1 Ø An absolutely clean surface, free of oil, grease, electrochemical or chemical conversion coatings, primer coatings, marking inks, scale, soil, and other foreign matter, is the prime requirement to ensure proper adhesion of the mask and uniform etching of the material. Because parts or stock received for chemical milling normally have surfaces contaminated with one or more of the above types of soil, it is recommended that standard cleaning procedures be established for each of the primary alloys and that the correct procedure be used on all parts prior to masking.

3.3.1.2 One or more of the following steps is required to satisfactorily clean the alloys of aluminum, magnesium, titanium, and steel.

3.3.1.2.1 Ø Solvent wiping and/or vapor degreasing are used to remove the visible oil or grease, primer coatings, and marking inks. Parts may be hand wiped using a clean rag and a fresh suitable solvent until the soil is removed (normally, solvent wiping is used to remove primer or marking inks) or the parts may be suspended in a standard vapor degreasing tank until degreased. Titanium alloys parts shall not be vapor degreased using halogenated hyrocarbon solvents. In either case, this step greatly prolongs the life of the alkaline cleaner solutions.

3.3.1.2.2 Ø Alkaline cleaners remove invisible oil, surface dust, traces of primer, marking inks, and minor inclusions which have been pressed into the surface in the forming or handling operations. High pH alkaline cleaners may cause excessive attack on aluminum alloy surfaces.

3.3.1.2.3 Scale, oxides, and conversion coatings must also be removed to ensure uniform mask adhesion. This is done by immersing the parts or stock in solutions which have been specially compounded for the specific task, such as the deoxidizers for aluminum alloys or the descalers for steel and titanium alloys.

3.3.1.3 The success of most chemical milling operations depends upon the efficiency of the rinsing steps. It is, therefore, very important that all parts be thoroughly rinsed immediately following each chemical treatment.

3.3.1.4 After cleaning, parts should be handled only with clean, cotton gloves to avoid recontamination with the natural oils present on the hands.

3.3.2 Masking:

3.3.2.1 Except where all-over metal removal is desired, all chemical milled parts should be masked as soon as possible after the parts have been cleaned, dried, and cooled to room temperature.

3.3.2.2 The mask is a coating of any kind which is used to control the location of the unetched or nonmilled areas of a part by protecting these areas from the action of the etchant solution.

3.3.2.3 A mask must have sufficient adhesion to cling tightly to the part when it is immersed in the etchant solution. A mask must also have sufficient adhesion to protect the edges of etched areas, thus producing good, sharply-defined, etched lines. The maskant must not adhere too tightly, however, or the mask will be difficult to hand-strip prior to etching.

3.3.2.4 Chemical milling maskants may be applied by dip, spray, flow-coat, roller-coat, or brush, or by silk screening for shallow etching.

3.3.3 Scribing and Stripping Etching Area:

3.3.3.1 The exposure of areas to be etched is accomplished by first cutting the mask along lines which define the areas, using a thin-bladed knife and then removing the mask, as desired, by hand stripping.

3.3.3.2 For single parts, layout tools are used to outline the areas to be scribed. High production schedules require the use of templates for this purpose. Constructed of sheet metal or glass laminate, a template is approximately the same size and contour as the part and fits snugly against the masked surface to be etched. The specific areas to be etched are defined by cut-out sections of the template.

3.3.3.3 Prior to scribing, the template is placed over the part, properly located according to index holes or tabs, and clamped securely against the masked part.

3.3.3.4 Scribing is an art which requires patience and skill. The flat side of the scribe knife blade is placed against the edge of the cut-out area of the template and held perpendicular to the surface of the part. Sufficient pressure is applied to penetrate the mask without scratching or gouging the metal beneath, and the blade is drawn along the outline to scribe completely the area to be etched as shown in Figure 3. Under cutting or overcutting the mask at the edge of the template results in changes in the line location on the etched part.

3.3.3.5 When scribing is complete, the template is removed and the mask stripped from the areas to be etched by peeling it away from the metal toward the center of the area to be etched. The scribed and stripped areas may be inspected for proper dimensions and any tendency of the mask to lift from the surface. Abnormalities which may cause rejection of the finished part can usually be repaired, but if they are too extensive, the part should be stripped completely, recleaned, and remasked.

3.3.4 Etching:

3.3.4.1 Immersion of a part in an etching solution to remove metal and leave a predetermined design is the basic operation of the chemical milling process. The cross section of the finished part may show tapers, selected reduction in certain dimensions, uniform reduction in all dimensions, or a combination of these configurations.

3.3.4.2 Tanks filled with special solutions constitute the chief equipment used in the etching operation. These tanks should be arranged to permit rapid transfer of parts from one to another as etching and surface finishing or rinsing proceeds. The tanks are constructed of materials which resist the action of the etchant solutions and are fitted with auxiliary equipment to permit control of the solutions and the fumes from the tanks.

3.3.4.3 Ø Etch tanks require several types of auxiliary equipment. Tanks should be fitted with heat exchangers for temperature control, agitation elements to aid in heat transfer as well as to maintain uniform concentration of chemicals throughout the tank and elimination of trapped gas and surface bubbles, and float controls or warning devices to maintain proper fluid level. A venting system above the tank is used to carry fumes away from the operating area.

3.3.4.4 Baskets or racks, used for simultaneous etching of smaller parts, may be shifted from tank to tank by an overhead monorail or bridge crane. Large parts which are impractical to rack may be handled individually by the crane.

3.3.4.5 Rinses and other solutions remove undesirable surface coatings or deposits formed by the action of the etchant solutions. A rinse system is, preferably, a combination deep-rinse tank with continuous overflow gutters and a low-pressure spray system above the overflow level. Agitation of water in the deep-rinse tank hastens rinsing action and reduces sludge or scale build-up in the tank. Most rinsing and surface finishing solutions are operated at or near room temperature, and, because the heat generated by chemical reaction with immersed parts is slight, heat exchangers are unnecessary.

3.3.4.6 To ensure uniform metal removal, etchants have been specially formulated which not only dissolve metal but also control sludge formation, etch rate, and surface finish.

3.3.4.7 For example, in aluminum etching solutions operated at high concentrations and temperatures, there is a tendency for metals, such as copper and zinc, to plate out on the surface being etched, producing irregularities on the surface or the formation of a hard sludge. To avoid these faults, aluminum etchants which produce smooth, uniformly etched surfaces with no sludge problem have been specially formulated.

3.3.4.8 Ø Because the depth of metal removed is dependent upon the time of immersion in the etching solution, the etch rate for a particular metal or alloy must be determined prior to production of parts. Etch rate is the depth of metal removed from a surface by the etching solution per unit time, expressed in mils (thousandths of an inch) per minute (millimetres per surface per minute). This unit is abbreviated to M/S/M. A general formula for determing etch rate is:

$E = \frac{s}{t}$, where E = etch rate, M/S per M (mils (millimetres)/surface per minute)

s = depth of metal removed per surface, mils (millimetres)

t = time required to remove "s" metal, minutes.

Practical etch rates range from 0.5 to 2.5 M/S per M (0.013 to 0.064 mm/S per M).

3.3.4.9 To determine the correct time of immersion in the etchant, the rate of each etch must be determined periodically through the work period and after any etchant additions are made.

3.3.4.10 The etch rate may be determined by immersing a small panel of material which corresponds to the material to be etched. For example, if parts of 2024-T4 alclad are to be run, the panel should be 2024-T4 alclad of approximately the same thickness. The test panel shall be cleaned and its thickness measured by micrometer. The panel shall be then immersed in the etchant solution, etched for not less than 10 minutes, removed, rinsed, dried, and its thickness again measured. If, in 10 minutes, 10 mils or 0.010 inch (0.25 mm) was removed from one side of the panel, the etch rate is 1 M/S/M determined as shown below:

$$E = \frac{s}{t} = \frac{\text{mils removed/side}}{\text{time}} = \frac{10\ (0.25\ \text{mm})}{10\ (10\ \text{minutes})}$$

$$= 1\ \text{Mil/Surface per Minute or } 1\ \text{M/S/M}\ (0.025\ \text{mm/S per M})$$

3.3.4.11 The time of immersion to remove metal to a given depth can now be determined according to the formula:

$$T = \frac{S}{E}$$

where, T = Time, in minutes, required to etch surface to desired depth

S = Mils (mm) of metal to be removed per surface

E = Etch rate of alloy in M/S/M (mm/S/M)

In the example mentioned, a 0.060 inch (1.52 mm) cut could be made in:

$$T = \frac{60\ \text{mils}}{1\ \text{M/S/M}}\ \frac{(1.52\ \text{mm})}{(0.025\ \text{mm/S/M})} = 60\ \text{minutes or 1 hour}$$

3.3.4.12 As soon as the operator becomes familiar with the etchant solution and etching process, he will know the approximate etch rate. He may, therefore, elect to determine the etch rate and immersion time using the production parts.

3.3.5 <u>Demasking</u>:

3.3.5.1 After the parts have been treated to remove smut, the parts are ready for mask removal. Hand stripping or any other mask removal method may be used provided the method is not detrimental to the base material.

3.3.5.2 To reduce handling effort and time spent in this operation, special demasking solutions have been prepared. The masked parts are immersed for a short time in the demask solution. These solutions swell the mask or loosen the mask-to-metal bond, or both, allowing the mask to be easily pulled off by hand.