

AEROSPACE RECOMMENDED PRACTICE

ARP1331™

REV. C

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Superseding ARP1331B

The Chemical Milling Process

RATIONALE

ARP1331C results from a Five-Year Review and update of this specification with the addition of alloys in the Scope (1), addition of Intended Use (1.3), added definitions of Hypermilling and Transition Zone (2.2), added application to additively manufactured metal parts (3.1.1), added application for removal of residual metal (3.1.6), added NOTE regarding residual stress (3.2.7.1), added two Advantages (3.2.13, 3.2.14), added three Limitations (3.3.9, 3.3.10, 3.3.11), added common milling techniques to Depth of Removal Tolerance (4.1.2.2.1), added suggestions for reducing bath heating for light weight applications (4.1.6.1), added Transition Zone limits (4.1.12), expanded materials for Template Materials (4.2.1), added an example for Undercut Rate (4.2.3), expanded requirements for Cleaning (4.3.1.1), added "copper" to list of materials that need specific cleaning steps performed (4.3.1.2), clarified rinsing instructions (4.3.1.3), added two limitations to Masking (4.3.2.5, 4.3.2.6), added two limitations to Scribing (4.3.3.6, 4.3.3.7), revised the etch/metal rate determination (4.3.4.10), added direct dimensional verification (4.3.4.13), added note regarding surface roughness (5.3), added ARP4992 to the notes for control of processing solutions, and added Figure 4 showing an example of transition zone.

1. SCOPE

This practice provides recommendations concerning the chemical milling of aluminum, magnesium, high temperature nickel alloys, titanium alloys, copper alloys, and specialty alloys.

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

1.2 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.

1.3 Intended Use

Although this document is designated as a recommended practice, when the term "shall" is used, the statement that it applies to is a requirement that shall be followed unless otherwise approved of by the cognizant engineering organization.

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2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP1917 Clarification of Terms Used in Aerospace Metals Specifications

AS2390 Chemical Process Test Specimen Material

ARP4992 Periodic Test for Processing Solutions

2.2 Definitions

Terms used in AMS are clarified in ARP1917.

2.2.1 HYPERMILLING

An out of control reaction that occurs when a localized area accelerates in terms of removal rate. This can occur due to inadequate agitation or flow, creating a bubble of gaseous reactant that permits higher enthalpy within the bubble, thereby increasing the etch rate exponentially until the unreacted etchant is consumed. In some cases, this effect occurs when the byproduct creates a scale or oxide layer that entrains gas beneath it against the surface and the result is the same.

2.2.2 TRANSITION ZONE

The transition zone is the distance from the edge of the milled cut to the point where the thickness of the chemically milled area becomes constant (see Figure 4).

3. 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.

3.1 Application of Chemical Milling Process

This process can be used as follows but is not limited to these applications:

- 3.1.1 Remove metal from the surface of formed or irregular shaped parts, such as forgings, castings, extrusions, formed wrought stock, or 100% dense additively manufactured (3D printed) metal parts. Metal may be removed from the entire surface of the part or from selected areas.
- 3.1.2 Reduce web thicknesses below practical machining, forging, casting, or forming limits.
- 3.1.3 Taper sheets and preformed shapes.
- 3.1.4 Produce stepped webs, resulting in the consolidation of several details into one integral piece.
- 3.1.5 Remove metal from the surface of tough, hard-to-machine alloys.

3.1.6 Remove residual metal from internal passageways/capillaries.

3.2 Advantages of Chemical Milling Process

3.2.1 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.

3.2.2 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.

3.2.3 Close tolerances may be held when chemically milling.

3.2.4 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.

3.2.5 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.

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

3.2.7 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.

3.2.7.1 NOTE: If chem milling of hardware that already has residual stresses within it (due to forming, heat treating, etc.), the milling amount needs to be relatively equal on both faces of the section or warping can occur during the process or after some time due to imbalance.

3.2.8 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.

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

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

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

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

3.2.13 Parts with internal geometries may also be processed individually or simultaneously with the external surfaces (see 3.3.7).

3.2.14 Chemical milling provides the opportunity to decrease metal thickness anywhere that liquid can flow efficiently.

3.3 Limitations of Chemical Milling Process

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

3.3.2 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.

- 3.3.3 Welded parts should 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.
- 3.3.4 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.
- 3.3.5 Surface waviness and thickness variations are reproduced but not enlarged.
- 3.3.6 Normally, removals in excess of 0.500 inch (12.70 mm) deep are not recommended.
- 3.3.7 Holes, deep and narrow removals, narrow lands, and sharp, steep tapers should not be attempted.
- 3.3.8 No one etchant can be used on all alloys. Caution should be exercised in selection of the etchant for the alloy being chemical milled.
- 3.3.9 In cast or forged parts, inclusions may become apparent following the chemical milling process as a result of external metal being removed or enhanced etching at the compositional inhomogeneity.
- 3.3.10 Internal cavities or passages that do not permit adequate flow can create uneven, hypermilled areas, or the possibility of residual retained etchant that can cause corrosion at some subsequent time.
- 3.3.11 Reducing roughness or kerf produced during machining or stamping.

4. RECOMMENDATIONS

4.1 Design Considerations

4.1.1 Depth of Removal:

Although removals up to 2.0 inches (51 mm) deep have been made in plate, the limitations in Table 1 may be used as a guide:

Table 1

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

4.1.2 Depth of Removal Tolerance

- 4.1.2.1 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 should be enlarged to allow for the thickness variations introduced by these operations, or these variations should be removed.
- 4.1.2.2 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 stock which are controlled to a closer tolerance by the producing mill.
- 4.1.2.2.1 Common milling techniques such as “washing or taper milling” may also permit reductions in excess range as a result of forming.