Machining Magnesium

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Illustrations and Tables

Basic Considerations

Magnesium is a lightweight metal, with a specific gravity of only 1.8. It is considered to be the lightest structural metal, also one of the easiest to machine. Although often chosen because of its lightness, the excellent machinability of magnesium is a valuable bonus benefit where a large amount of machining has to be done.

Magnesium can be machined at high speeds and feeds, giving significant savings if machining represents a major cost in producing a given part. The low cutting pressures and high thermal conductivity of the metal permits rapid dissipation of heat. These benefits provide long tool life, dimensional accuracy of the part, and a fine surface finish.

Table 1 lists the relative machinability of some common metals compared to magnesium taken as the base unit. It is based on the power to remove a given amount of metal. The various alloys of magnesium require from .15 to .30 horsepower per cubic inch.

TABLE I — Relative Power Required to Machine Metals.

Metal	Relative Power Required (I = lowest)
Magnesium Alloys	1 0
Aluminum Alloys	1 8
Brass	2 3
Cast Iron	3 5
Mild Steel	6 3
Nickel Alloys	10 0

Magnesium's ease of machining makes it superior to other metals because it:

1. Reduces machining time — requiring fewer machines, less capital investment, and less floor space to do the same job; also lower labor and overhead costs.
2. Increases tool life by four to five times with resultant lower tool costs and less "down time" for tool changing.
3. Requires only one cut to give an excellent surface finish instead of two or more.
4. Leads to less tool build-up.
5. Minimizes chip handling costs with its well broken chips.

The superior machinability allows modern machine tools to be used at maximum capacities and allows higher rates of feed. The lower power required permits heavy depths of cut at these high speeds.

Chip Formation

The type of chip formed during machining depends on such factors as the composition, form, and temper of the alloy used, and the rate of feed. Rake angles and cutting speeds influence chip formation to a high degree when machining other metals, but have little or no effect on magnesium. The three general types of chips produced with single point tools during turning, boring, shaping, and milling are shown in Figure 1. Alloys in cast form are likely to yield chips of types A and B, depending on heat treatment. Forgings and extrusions yield chips of types B and C depending on the rate of feed employed. Long, curled chips of type C show the ductibility of the alloy.

Tool Material

The selection of a tool material for machining magnesium depends on the amount of machining to be done. Ordinary carbon steel tools have exceptional lives, but are not recommended for high production jobs. Experience has shown that high speed tools will last as long on magnesium as carbide-tipped tools will last on other metals. For high production jobs, high speed steel tools give excellent tool life. Those of long duration also justify the higher cost of carbide-tipped tools, as the longer tool life will offset the higher initial cost. The hard, abrasion-resistant grades of any of the commercial brands of carbide material are satisfactory. Diamond-tipped tools are usually not necessary when machining magnesium, although they have been effectively used when fine surface finishes of three to five microinches were required.

Tool Design

Tools should be ground to recommended angles to take advantage of the excellent machining characteristics of magnesium. Special attention should be given to relief and clearance angles. These angles should be as large as possible to keep the areas of the tool behind the cutting edge from rubbing on the work and causing excessive heating and tool build-up. Larger clearance and relief angles than are usually permitted can be used on

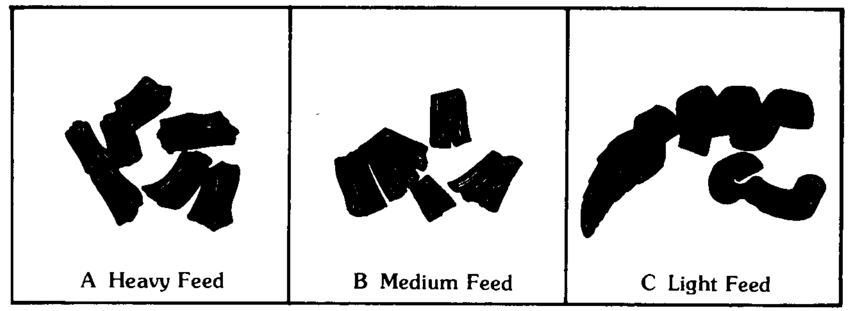


Fig. 1 — Magnesium chip formation.

tools for magnesium because of the cutting pressures. Cutting pressure is greatly affected by cutting tool angles, especially rake angles. Decreasing the top rake angle of a turning tool from 25° to 15° can increase the cutting pressure by as much as 50 percent. An increase in the rake angle will naturally decrease cutting pressure, but at a sacrifice in tool life. For maximum tool life, back rake angles can range up to around 20°. Rake angles on carbide-tipped tools should be smaller than on high speed steel tools to reduce the possibility of chipping. End and side cutting edge angles are usually not too critical and are best determined by the requirements of each job. Extremely large side cutting-edge angles may cause tool chatter. The nose radii of tools can be somewhat greater than those used on other metals, permitting greater feeds for a given surface finish. Specific tool angles for a given machining operation are provided in the section which describes that particular machining operation in detail.

Tool Grinding

A very important rule is that tools must be kept sharp when machining magnesium. Rough grinding of cutting tools may be done on medium grade wheels; however, to provide smooth tool faces and good cutting surfaces, finish grinding should be done on fine grain wheels. Aluminum oxide 100 grit wheels are satisfactory for finishing high speed steel, although finer grits produce smoother finishes. Silicon carbide 320 grit wheels or 200 to 300 grit diamond wheels are used for finishing carbide-tipped tools.

To insure long tool life and excellent surface finish on parts, careful hand honing should be done to remove the burr and grinding wheel marks. It is imperative that surfaces on the clearance angles and all areas over which chips pass be well polished to minimize tool build-up. This is particularly important in high production machining operations. Drills for deep-hole drilling should have polished flutes as well.

Cutting tools that have been used on other metals, even for only short periods, should be reground and honed before use to insure best performance on magnesium.

Often, a simple visual inspection cannot detect whether a cutting edge is sharp enough to give satisfactory service. Indications that tools need sharpening or replacement are:

1. An inability to hold tolerances and give good finish on the part.
2. The generation of excessive heat.
3. A formation of long chips with burnished surfaces.
4. A flashing or sparking at the tool edge.

Sharpened tools should not be operated to the full extent of their potential life, but should be resharpened when only slightly dull to maintain good cutting edges and conserve tool material. Many shops doing production machining operate tools for a pre-determined length of time and then replace them with freshly sharpened tools.

Tool Life

A study based on both wet and dry machining of magnesium and aluminum in U.S. industries showed a five to ten times greater life of cutting tools for magnesium than for aluminum. A European study of high production automotive machining showed a four to five times greater tool life for magnesium than for aluminum. This study, however, was based on machining magnesium dry, and cooling aluminum with a water-soluble oil.

Several machining installations for magnesium in the U.S. today have machined as many as 900,000 or more auto parts without changing or sharpening the cutting tools. Drill life equivalent to 115,000 diameters of depth per sharpening at feeds up to 0.010" per revolution have also been reported.

Machining Practice

Magnesium can be machined in production on many types of machine tools, including small, manually-operated lathes, milling machines, drill presses, etc. It can also be machined on large, specially-built, high production, completely automated transfer machines operating at high production rates.

Dry Machining

Magnesium is machined dry or with a coolant. Dry machining usually is cleaner, more profitable, and therefore more desirable than with the use of a coolant. Most major shops machine magnesium without the use of coolants. Safe, efficient chip removal is important when dry machining. The cutting tool zones of single unit and transfer machines must be as free as possible of obstructions and pockets to insure a smooth flow of chips to the collection area. Chip shields, beveled pallets, slanted machine beds, and blow-off chambers are used to minimze chip accumulation on the machine. In transfer machines, screw conveyors under the length of the machine remove chips to a collector. Dry machining is preferred in turning and boring, drilling, milling, shaping and planing, and other operations involving machines of relatively simple design where the operator can visually observe and extinguish a fire, should one start.

Coolants

The improved surface finish and increased tool life which cutting fluids accomplish for many metals are minor considerations in most machining operations on magnesium. If required, such fluids are used mostly to cool the work, minimize the possibility of distortion of the part, and reduce the chances of ignition of fine chips during grooving or similar operations. Consequently, these fluids are referred to as "coolants" when used during the machining of magnesium. In very high production operations as in the automobile industry, however, coolants do become a factor in providing increased tool life.

When tapping and reaming, there is the possibility of chip jamming. Coolants can help flush away the chips and may actually increase tool life. In the more complicated boring machines and transfer machines, designed for metals other than magnesium, it is more difficult to visually detect a fire and it is often desirable to use a coolant to wash the chips out of the machining area and into a collection sump.

Coolants should always be mineral oils since animal or vegetable oils are not suitable for use on magnesium. *Water-soluble oils, oil water emulsions, or water solutions of any kind, while good coolants should not be used on magnesium.* These coolants would severely intensify a fire in magnesium

TABLE II — Properties of Coolants Recommended for Machining Magnesium.

Property	Value
Specific Gravity	0 79 to 0 86
Viscosity (Saybolt) at 100°F	up to 55 sec.
Flash Point — Min. Val. (closed cup)	• 275°F
Saponification No (max.)	16
Free Acid (max.)	0 2%

NOTE Water soluble oils, oil-water emulsions, water or water solutions of any kind should NOT be used when machining magnesium Water wet magnesium turnings and chips greatly intensify chip fires that may be started when safe handling methods for magnesium have not been practiced Water soaked chips are also of no value to scrap buyers

chips, should one start. Magnesium chips, wet with these coolants, present a serious hazard in storage and have little, if any, scrap value. Mineral seal oil and kerosene have been used with success as coolants for machining magnesium. Mineral oil base cutting fluids having relatively low viscosity are also satisfactory. Table II lists the various properties of these mineral oil coolants.

Thermal Expansion

Certain physical characteristics of magnesium must be taken into consideration during machining. Because of magnesium's high specific heat and good thermal conductivity and diffusity, the input frictional heat is rapidly diffused throughout the entire part and consequently the usual temperatures developed when cutting magnesium are quite low. With high machining speeds and feeds, however, considerable heating of the part can occur if a large amount of metal is removed. When appreciable heat is generated under such conditions, the relatively high coefficient of thermal expansion of magnesium must be taken into consideration if close tolerances are required on the finished part. The mean coefficient of thermal expansion in the temperature range of 68° - 392°F ranges from 0.0000148 to 0.0000152 for various magnesium alloys.

Clamping and Distortion

Clamping should always be done on the heavier sections of a magnesium part. Care should be taken that clamp pressures are not high enough to cause distortion. Use shims between the part and tool bed when necessary. Take special care with light parts which might be distorted easily by the pressures in a chuck or clamp, or while making heavy cuts. Distortion or warpage of magnesium parts due to cold working during machining seldom occurs and can usually be traced to poor machining practices. These poor practices include the use of dull tools, slow feeds, tool dwell, or any operation that heats the part excessively. Cold working due to poor machining practices can build up extremely high stresses in the surface to a depth of as much as 0.020". Such stresses tend to distribute themselves throughout the part and can cause warpage. Warpage as a result of cold working during machining may appear shortly after removing clamps, or it might not show up until after several days or months of storage. It may also show up during the application of a baked paint coating.

Rough cuts are more likely to induce cold working into the part than fine finishing cuts. Stress relieving may be advisable after rough machining on complex parts or on parts where extremely close tolerances are required. The times and temperatures for stress relieving are shown in Table III. Parts should be cooled at a slow uniform rate from the temperatures shown. The rough machining can be carried down to within 0.020" and 0.025" of the final dimension desired, and the balance removed with one or two finishing cuts after the stress relieving operation. Stress relief should be used only as a last resort because frequently two finish cuts removing up to a total of 0.020" serve to remove the high stressed layer induced by the rough machining. The lower stresses that might be induced by the finish cuts are not likely to cause warpage.

TABLE III — Stress Relieving after Machining.

Wrought Alloys	
AZ31B-F, -0	1 to 4 hrs. at 400°F
AZ31B-H24	1 to 4 hrs. at 275°F
AZ61A-F	1 to 4 hrs at 400°F
AZ80A-T5	1 to 4 hrs at 400°F
ZK21A-F	1 to 4 hrs at 400°F
ZK60A-F	1 to 4 hrs at 400°F
ZK60A-T5, -T6	4 hrs. at 300°F

Safe Machining Practice

The magnesium fines produced during certain machining operations can present a fire hazard. Magnesium alloys must be heated to near the melting point before ignition can occur. Rough cuts and medium finishing cuts produce chips of a size that cannot be readily ignited during machining. Fine finishing cuts, however, yield fine chips which are subject to easy ignition. Such practices as stopping the feed and letting the tool dwell before disengagement, or letting the tool or tool holder rub on the work can produce a combination of fine chips and excessive frictional heat.

Factors which tend to increase the chances of fine chip ignition include:

a) Cutting speeds above 600-700 SFM in combination with extremely fine feeds

b) Dull or chipped tools

c) Improperly designed tools

d) Incorrect machining practices

e) Tool striking on an iron or steel insert in the magnesium part

f) Tool breakage

At high cutting speeds, the chances of fire are remote, unless feeds are less than 0.010" per revolution. Under the most adverse conditions, which would be the use of dull tools and fine feeds, the chances of chip ignition are very slight at feeds below about 400 SFM.

The fire hazard associated with the machining of magnesium can be controlled, and many shops are machining large quantities of magnesium every day without difficulty. Machine tool operators should not become alarmed at the brilliant white light with which magnesium burns and should observe the following rules:

1. Keep all cutting tools sharp and ground with adequate relief and clearance angles.
2. Use heavy feeds to produce thick chips.
3. Avoid fine feeds and do not permit tool to rub on the work.
4. If chip ignition presents a problem, when taking fine cuts, use a mineral oil coolant.
5. Practice good housekeeping; keep machines and work areas clean, storing magnesium chips in plainly labeled, covered non-combustible containers. Machinists should not wear coarse textured or fuzzy clothing; and chips, filings and fine dust should not be allowed to accumulate in cuffs or pockets.
6. Keep an adequate supply of recommended fire extinguishers for magnesium fires within easy reach of all machine tool operators.

In the event of a fire in magnesium chips, it should be extinguished as follows:

a) Apply a layer of either G-1 or Met-L-X powder over the fire. (Both extinguishers are U.L. listed.) Clean, dry cast iron chips, free from rust, also may be used.

b) A magnesium fire on a combustible surface like a wood floor, should be covered with a layer of the extinguishing powder and the entire mass shoveled into a dry iron container or onto a dry piece of steel plate.

c) The operator must never use carbon dioxide, water, foam, or other liquid type fire extinguishers on magnesium chips. These materials will intensify the fire and could be dangerous.

Turning and Boring

A wide range of cutting speeds, feeds, and depths is possible when turning or boring magnesium. Speeds up to 5,000 SFM have been used at feeds of 0.030" or more per revolution. It is not necessary, however, to machine magnesium at these high rates to produce more parts per hour than is possible with any other metal. The actual machine cutting time in a properly set up piece of equipment is at least 50 percent less than any other light metal. The advantage over heavier metals is even greater. In rough machining operations, feeds up to 0.020" or more per revolution are used in production at speeds up to 3,000 SFM. If speeds are kept below 1000 SFM, feeds can be increased up to 0.080" per revolution or higher.

Magnesium is finish machined in production with feeds in the range of 0.005" to 0.010" per revolution. Speeds will range up to 2500 SFM.

The requirements of surface smoothness will usually determine the feed limit. When surface smoothness requirements are the same, magnesium can be turned and bored at feeds somewhat greater than those used for aluminum. This is due in part to the lower cutting pressures encountered during the machining of magnesium. Table IV gives the range of feeds, speeds, and depths of cut for turning and boring magnesium.

Extremely fine cuts should be avoided whenever possible, since they tend to heat the work more than the heavier cuts. Avoid turning and boring a diameter at the end of cut when it is necessary to butt the tool into a shoulder. This causes a shaving action which produces a fine ribbon. These fine ribbons will accumulate in a fluffy mass of turnings which are easily ignitable.

TABLE IV — Speeds, Feeds and Depths of Cut for Turning and Boring Magnesium.

Operation	Speed fpm	Feed ipr	Maximum Depth of Cut inches
Roughing	300 to 600	0.030 to 0.100	0.500
	600 to 1000	0.020 to 0.080	0.400
	1000 to 1500	0.010 to 0.060	0.300
	1500 to 2000	0.010 to 0.040	0.200
	2000 to 5000	0.010 to 0.030	0.150
Finishing	300 to 600	0.005 to 0.025	0.100
	600 to 1000	0.005 to 0.020	0.080
	1000 to 5000	0.003 to 0.015	0.050

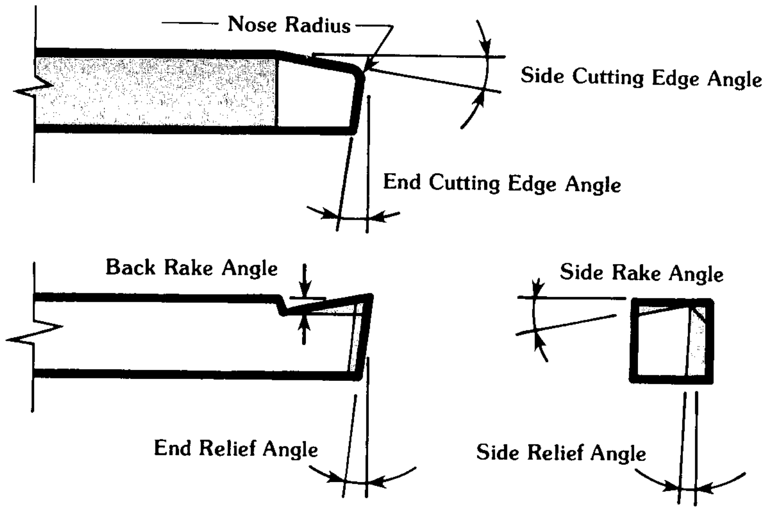


Fig. 2 — Terminology of single point tools according to American Standards Association.

Cutting tools used on magnesium should have relief and clearance angles that are sufficiently large to eliminate contact and rubbing of the tool beyond the cutting edge. The light cutting pressures required for magnesium permit large clearance angles with minimum support for the cutting edge.

Figure 2 shows the terminology of single point tools established by the American Standards Association. Proper tool geometry for single points for turning and boring tools for magnesium are shown in Figure 3 for both roughing and finishing tools. The top and relief or clearance angle surfaces

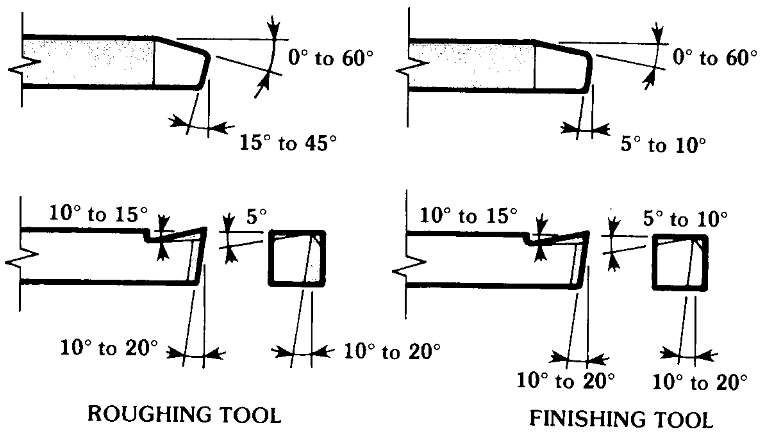


Fig. 3 — Typical turning and boring tool geometry for magnesium.

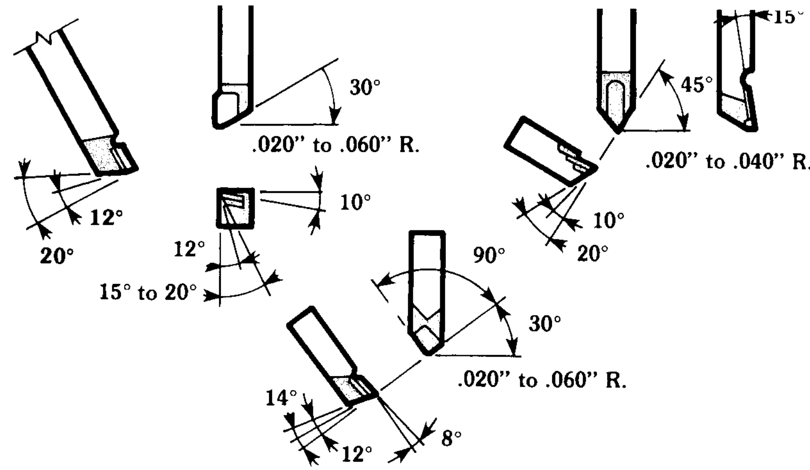


Fig. 4 — Typical turning tool geometry for magnesium.

should be honed to a fine finish for best results. The cutting-edge angles, end relief and side relief angles and nose radii of typical turning tools are shown in the drawing of Figure 4. Tool position generally is at or slightly above the center line of the work piece.

Some flashing may occur with grooving or parting tools because they cut on the front and rub on the sides. These tools require special treatment. In the tool geometry shown in Figure 5, the tool is given relief on the sides to minimize the generation of fine dust and excessive heat.

If sparking or flashing occurs, even though the tool is properly ground, apply a mineral oil coolant. The tool should never be allowed to dwell at the end of the cut; it should be advanced into the work as rapidly as possible and removed the same way.

Surface finishes of 10 microinches or less can be readily obtained in production turning and boring operations by following the suggested procedures. It is common practice in production to hold a 20-30 microinch finish without problems.

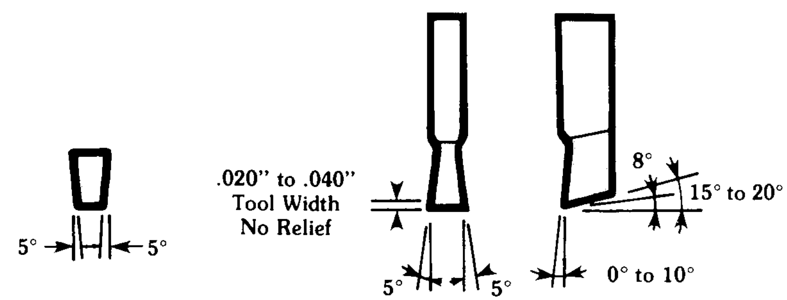


Fig. 5 — Grooving Tool for Magnesium.

Milling

Milling operations provide an opportunity to take full advantage of the excellent machining characteristics of magnesium. Extremely high speeds and heavy feeds remove metal rapidly and produce an excellent surface finish. Rough milling operations are carried out at speeds in the range of 1,000 to 3,000 SFM at feeds from 0.002" to 0.010" per tooth. High speed steel and carbide-tipped tools can be used successfully on magnesium. However, the carbide is preferred on high production jobs.

A typical bit for an inserted tooth rough face milling cutter is shown in Figure 6. The cutter is set in the milling head at a 10° angle. Milling cutters such as these operate in production at speeds of 3200 feet per minute with feeds of 0.002" to 0.004" per tooth. Figure 7 shows a typical finish milling cutter bit for magnesium. This cutter is set at a 10° angle in the mill and produces an extremely fine finish on the magnesium part when operating at a speed of 4800 SFM, with a feed of 0.002" per tooth.

General finish milling in production is normally done in the speed range of 1,000 to 3,000 SFM. Feeds are as great as the requirements for surface finishing will permit. Table V is a guide to feeds, speeds, and depths of cut used when milling magnesium. This table should be considered as a guide only. The values can vary substantially.

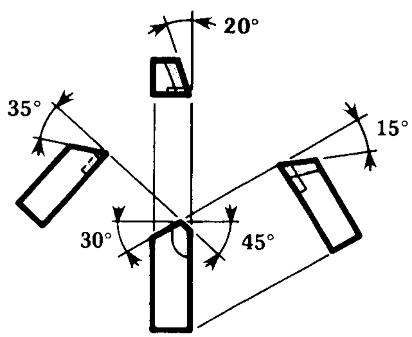


Fig. 6 — Typical carbide insert cutter bit for inserted type rough face milling cutter.

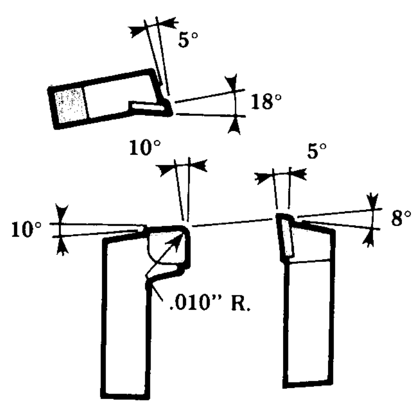


Fig. 7 — Typical carbide insert cutter bit for inserted type finish face milling cutter.

TABLE V — Speeds, Feeds and Depths of Cut for Milling Magnesium.

Operation	Speed fpm	Feed in./min.	Feed in./tooth	Depth of Cut inches
Roughing	up to 900	10 to 50	0.005 to 0.025	up to 0.500
	900 to 1500	10 to 60	0.005 to 0.020	up to 0.375
	1500 to 3000	15 to 75	0.005 to 0.010	up to 0.200
Finishing	up to 1000	10 to 50	0.005 to 0.015	up to 0.075
	1000 to 3000	10 to 70	0.004 to 0.008	0.005 to 0.050
	3000 to 5000	10 to 90	0.003 to 0.006	0.003 to 0.030
	5000 to 9000	10 to 120	0.002 to 0.005	0.003 to 0.030

Inserted tooth milling cutters have very large chip spaces to provide for ready removal of the large volume of chips produced. Single and multiple tooth fly cutters are particularly well suited for machining magnesium because they can be operated at the highest possible speeds, and there is no concern about inadequate chip space. The 2-blade fly cutter shown in Figure 8 is an example of an actual design used successfully on magnesium.

Milling of magnesium should be at feeds as heavy as the surface finish requirements will permit. This produces large chips which have more heat capacity. These large chips draw the heat from the work, and reduce the fire hazard that is present when extremely fine chips are produced. Slab, side cutting, and straddle milling cutters should be coarse toothed, with one-half to one-third as many teeth as similar milling cutters used on steel.

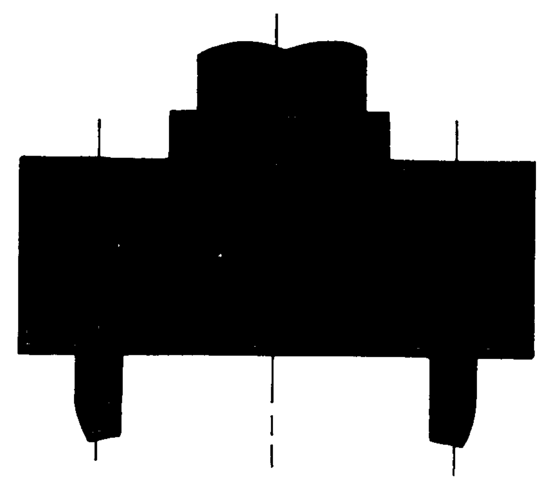
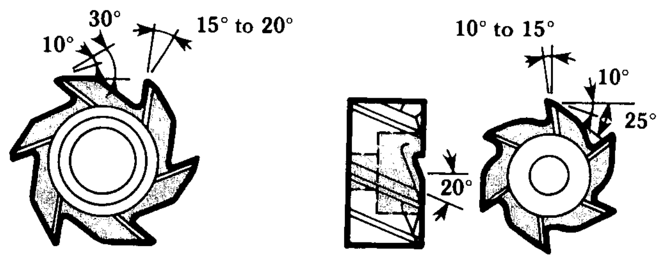


Fig. 8 — Two-blade fly cutter for high speed milling operations.

Figure 9 shows the suggested angles for a coarse tooth milling cutter and a shell end mill. Negative back rake angles are sometimes used on face mills to throw the chips out of the cutter. This type of cutter is normally operated at speeds of about 1,000 SFM, at feeds up to 0.010" per tooth.

Like other machining operations, milling of magnesium usually is done dry. The need for a coolant will depend upon the amount of heat generated by the type of milling operation and tooling. Mineral seal oil should be used as suggested in the section with coolants, page 8.



COARSE TOOTH MILLING CUTTER

SHELL END MILL

Fig. 9 — Typical milling cutters for use on magnesium.

Shaping and Planing

Single point tools are used for shaping and planing, using substantially the same tool geometry as recommended for turning and boring. Deviations from the recommended tool design can be made as long as cutting edges are kept sharp and adequate relief angles are used.

The maximum cutting speeds for shaping and planing are much lower than those recommended for turning and boring. Therefore, operating economy is accomplished by means of heavy feeds and depths of cut. These are possible as a result of the lower power required to machine magnesium. The only factors that limit the maximum size of cut during shaping and planing are the rigidity of the work piece, clamping fixtures, and the need for eliminating machining stresses in the work.

During shaping or planing, the tool block should be lifted on the return stroke of the ram to avoid dragging the tool over the work and marring the surface.

Drilling

Magnesium and its alloys can be drilled with standard general purpose drills. In some cases, it is advantageous to use modified drills or drills designed specifically for magnesium. These are for shallow or deep hole drilling, and sheet drilling. Feeds and speeds shown in Table VI are possible with magnesium, but many machine tools are not capable of operating at the high spindle speeds involved.

A study of numerous production operations where tool life, surface finish to the part, tolerances, machine wear, and other factors were taken into consideration, shows that usual speeds range from 150 to 400 SFM at feeds in the range of 0.005" to 0.015" per revolution. A study of the limiting or control cuts on transfer machine drilling shows that while the speeds are in the same range, the range of feeds is increased to 0.006" to 0.020" per revolution.

Shallow Hole Drilling

Holes up to depths of five times the drill diameter are considered shallow holes. Standard 118° point angle drills work very well, especially if the chisel edge is reduced to about one-half that of a general purpose drill. The helix angle of a standard drill is usually about 25°, but can vary from 10° - 30°. Flutes should be highly polished to facilitate the flow of chips out of the hole. This is especially important if low helix angle drills are used. The chisel edge angle can range from 120° to 135°. The 118° point angle should have a relief angle of approximately 12°. The cutting-edge corners should be rounded slightly for best surface finish and tolerance. Cutting edges should be kept sharp. Excessive burring, undersize holes, and heating tendency can be caused by dull drills. Figure 10 summarized shallow hole drill data.

Deep Hole Drilling

Holes over five times the diameter of the drill are considered deep holes. For best results, drills specifically designed for the purpose are recommended. The drilling of deep holes produces an appreciable quantity of chips, which must be removed from the hole through a considerable length of flute. At the high drilling speeds which are possible, the chips should be removed rapidly. This is accomplished by using a high helix drill like the one shown in Figure 11. Flutes should be highly polished to facilitate chip removal. It is common practice in deep hole drilling of magnesium to go as much as 20 times the drill diameter in one pass without removing the drill to release chips in the flutes.

TABLE VI — Speeds and Feeds for Drilling Magnesium.

Drill Diameter inches	Speed fpm	Feed — ipr		
		Sheet	Shallow Holes	Deep Holes
¼	300	0 005 to 0 030	0 004 to 0 030	0 004 to 0 008
½	to	0 010 to 0 030	0 015 to 0 040	0 012 to 0 020
1	2000	0 010 to 0 030	0 020 to 0 050	0 015 to 0 030

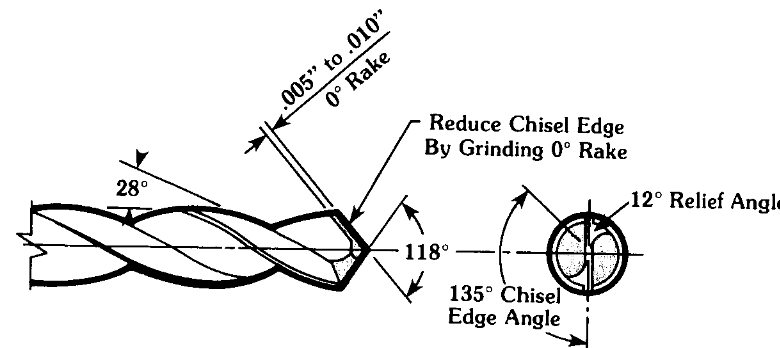


Fig. 10 — Modified standard drill for drilling shallow holes.

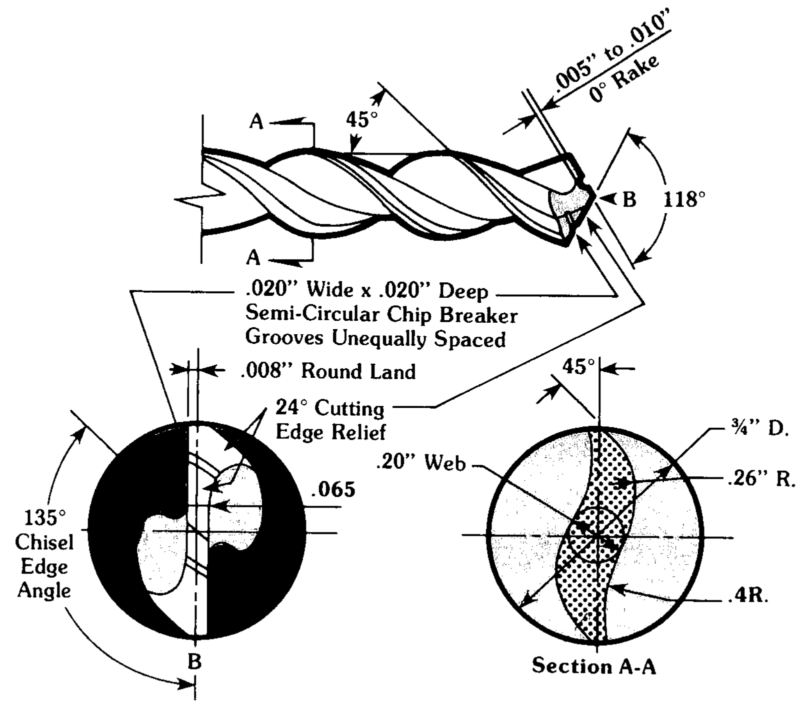
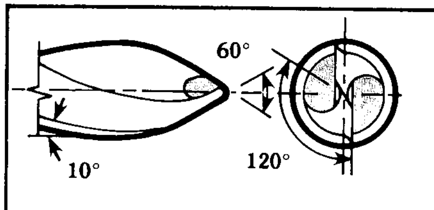


Fig. 11 — Typical design of ¾" diameter drill for deep hole drilling magnesium.

Drills for deep hole drilling of magnesium should have a helix angle in the range of 30° to 45° with open polished flutes. The web of the drill should have a constant thickness for the entire length of the flute, so that flutes are large at the top as well as the bottom of the drill. A chisel edge angle of 135° insures good surface finish and minimizes spiralling in the hole. The standard point angle of 118° should have a 24° relief angle. Chip breaker grooves are advantageous on deep hole drills over one-fourth inch in diameter. This tool geometry on a high helix drill will have a feathery cutting edge which will drill rapidly. When the chisel point is reduced, it should be done such that the same grinding operation puts a 0° rake angle on the cutting edge that is 0.005" to 0.010" in width. This will improve tool life considerably and produce well-broken chips.

Sheet Drilling

Magnesium sheet can be drilled with a sharp standard 118° point angle drill. A slightly modified general purpose drill should be used for high production of accurate holes with a good finish and minimum burr. The point angle should be reduced from 118° to 60° to prevent "walking" of the drill, to reduce thrust, and to prevent abrupt changes of thrust on the breakthrough. The chisel edge angle can be in the range of 120° to 135°, as is the case with standard drills. The web should be thin and the ends of the cutting edges rounded. A thin web at the point helps to center the drill and reduce thrust, while the round corners provide a smooth finish and reduce burrs. A low helix angle of approximately 10° helps to prevent the work from climbing the drill when breaking through. Figure 12 illustrates a drill recommended for use with magnesium sheet.



Drill Element	Recommendation
Point Angle	60°
Helix Angle	10°
Chisel Edge Angle	120 to 135°
Web	thinned at point
Corners	rounded

Fig. 12 — Sheet drill data.

Reaming

Reamers for magnesium should have fewer flutes than those for other metals. This will provide more chip space. Reamers under one inch diameter usually have four to six flutes. There should be an even number of flutes with opposing cutting edges spaced at 180°. When reamed holes with a fine finish are required, it is advantageous to keep the opposing pairs of cutting edges spaced at 180°; however, the pairs should be unequally spaced to a slight extent to minimize chatter. This is shown in Figure 13 which illustrates a reamer for use with magnesium.

The chamfer used on reamers is usually 45° and the rake angle is 7°, with a 0.006" to 0.012" margin (no relief). This is followed by a primary relief angle of 5° to 8° and a generous secondary relief angle. The flutes can be straight (0° helix angle) or have a negative helix angle of 10°. When the hole is drilled for reaming, sufficient stock allowance should be left so that the reamer will take a definite cut of 0.010" to 0.015". More stock than this may tend to build up in the flutes and will eventually jam the reamer. High speed steel or inserted carbide reamers can be used on magnesium. The choice depends upon the amount of production anticipated.

Magnesium can be reamed at speeds up to 400 SFM with feeds up to 0.040" per revolution. In general production practice, the speed range is 50-200 SFM, with a feed as high as possible while yielding the required surface finish. Tool life of reamers in magnesium is commonly as many as 15,000 to 20,000 holes.

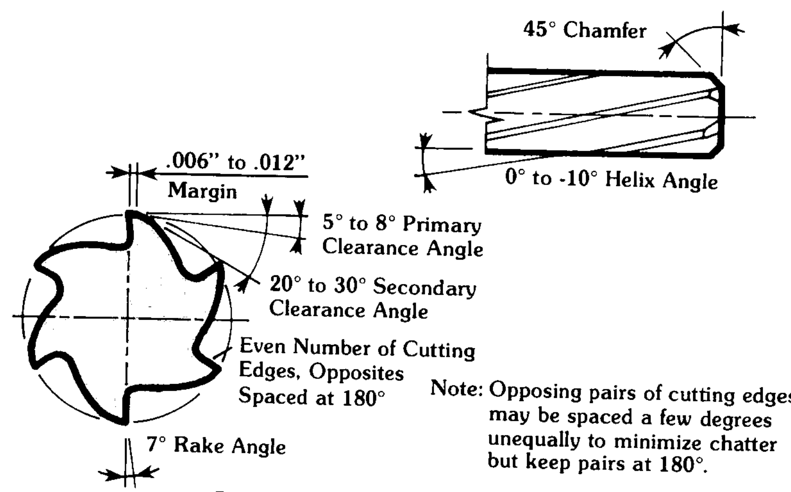


Fig. 13 — Reamer for magnesium.

Counterboring and Countersinking

High speed steel or inserted carbide counterbores and countersinks can be used on magnesium, depending on the amount of production anticipated. Margins should be small, with adequate relief and clearance angles to eliminate rubbing and provide for adequate chip space. It is highly desirable that counterbores have chamfered or rounded corners at the ends of the cutting edges. This eliminates the formation of sharp interior corners which can cause stress concentration.

Primary relief angles range from 0° to 15° and are followed by secondary relief angles up to 50°. Typical counterboring and countersinking tools for use on magnesium are shown in Figure 14. Speeds, when using these tools, are in the range of 100 to 300 SFM, with feeds averaging about 0.010" per revolution, but going as high as 0.020" per revolution. All cutting edges and margins should be kept sharp and highly polished. Like most machining on magnesium, counterboring and countersinking are usually done dry.

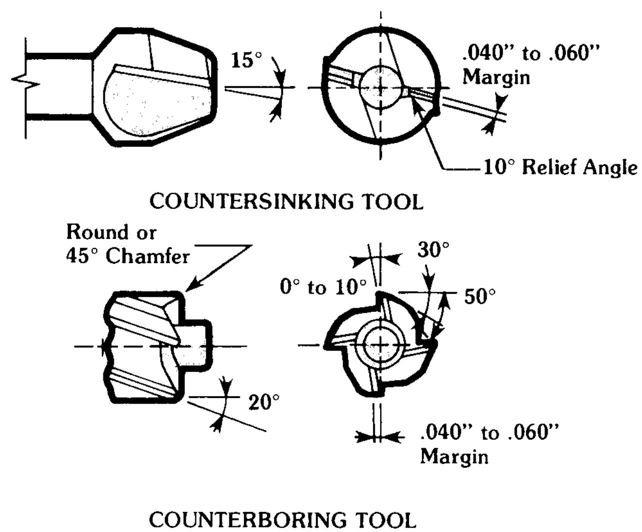


Fig. 14 — Typical counterboring and countersinking tools for magnesium.

Tapping

Standard taps can be used for magnesium for small runs or when close tolerances are not required. For high production or for close tolerances, however, it is necessary to modify standard taps or obtain those designed especially for magnesium. The recommended taps are of high speed steel, straight or the helical fluted concentric type as shown in Figure 15. The number of flutes can be determined by limiting the total land width to approximately 30 percent of the tap circumference. In normal practice, taps with two flutes are used up to 3/16" diameter, three flutes up to 3/4" and over. Taps must be kept sharp and the flutes should be well polished. Usually the tap design shown in Figure 15 gives good results from the standpoint of both finish and tolerance. Should trouble be encountered due to chips jamming when the tap is removed from the tapped hole, the use of a heel rake of 3° to 5° is recommended, as shown in Figure 16. This provides a cutting action when the tap is backed out and results in a clean, accurately

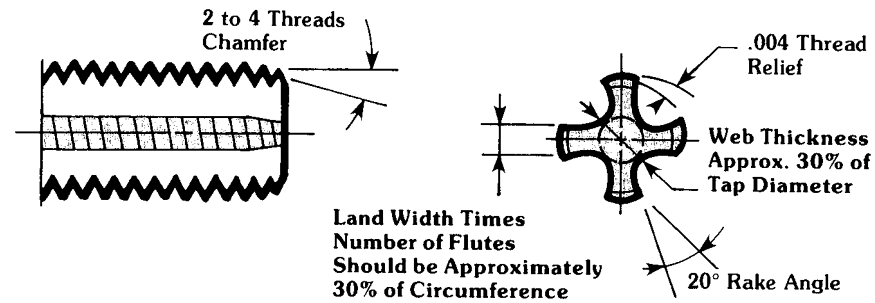
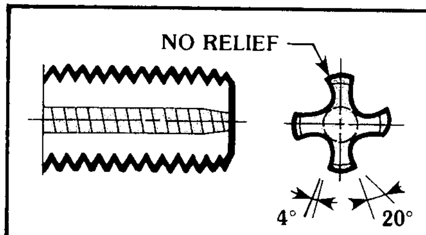


Fig. 15 — Typical tap for magnesium.



Tap Element	Recommendation
Rake Angle	10 to 20°
Heel Rake Angle	3 to 5°
Chamfer	2 to 3 threads
Lands	Cylindrical and Narrow
Flutes	2 to 4

Fig. 16 — Heel cutting tap for magnesium with no form relief.

oversize, the rake angle should be decreased. Conversely, increasing the rake angle will make the tap cut somewhat larger.

Magnesium can be tapped at speeds of 75 to 200 SFM, but in general practice, where the tapping operation is not the limiting or control cut on a transfer machine, speeds of 50 to 75 SFM will give the best results. Excellent quality tapped holes can be obtained without the use of a coolant since the magnesium does not build up in the flutres or on the cutting edges. The use of a mineral oil coolant as a lubricant, however, extends tap life considerably in high production applications.

Thread forming or express taps on magnesium are not advisable unless a 45 percent full thread will have sufficient stability and holding power. Magnesium does not form sufficiently at room temperature to obtain a higher percentage of full thread without cold working embrittlement and consequent spalling of the metal. Due to the excellent machinability of magnesium, the life of thread cutting taps on magnesium exceeds the life of thread forming taps on other metals, so there is no disadvantage here, other than that of removing chips from blind holes.

Threading

Threading dies for use on magnesium should have approximately the same cutting angles as taps. A cutting edge relief of 0.004" is advisable, although there may be parts requiring extremely fine surfaces and close tolerances where a 3° positive rake angle on the heel side of the land will clean up the thread when the die is removed. Self-opening die heads are used to give threads with maximum smoothness.

The cutting angles of thread chasers should be about the same as those used on single point turning tools, with the exception that the rake angle should be somewhat larger. Particular attention should be paid to the sharpness of the cutting edges and the relief angles. Threads may be chased in magnesium alloys at speeds up to 500 SFM and higher.

Sawing

Magnesium is readily cut with band or circular saws as well as with hand or power hacksaws. Because of low cutting pressure, larger cuts can be taken per tooth than are possible with other metals. This factor requires larger chip spaces to permit saws to remain free cutting. Too small a tooth pitch or chip space causes the saw to ride over the work and rapidly dulls the teeth. The set of the teeth on band and hacksaws must be relatively large, but no set is recommended for circular saw teeth. The relief angles on circular saw teeth must be adequate to minimize friction. Circular saw blades may be of high speed steel or may be made with tungsten carbide tooth inserts.

High speed steel circular saw blades are limited to less than 2,000 feet per minute peripheral speed, while carbide tipped blades may be operated as fast as 10,000 feet per minute. Sawing feeds are best determined by the requirements of the particular job and the type of sawing equipment used. A rough estimate of the allowable feeds may be based on the fact that magnesium requires only one-tenth the power that is required for sawing steel. A 12" carbide-tipped blade of the proper design can easily cut 250 linear inches per minute of 1" plate.

For general cutting where the circular saw blade penetrates the plate being split, the teeth should have square tops with the face either straight or 5° alternate bevel as shown in Figure 17. This example shows a carbide-tipped 12" diameter blade for cutting plate. The blade has 10° end relief, 5° rake, 48 teeth and operates at 1880 rpm (5900 SFM). For slotting operations, where the blade does not penetrate the plate being cut, a triple chip blade with alternate chamfered roughing tooth as shown in Figure 18 is used to provide both cutting and clearing of the slot. In this example, a 12" diameter, 72 tooth high speed steel or carbide tipped blade is shown.

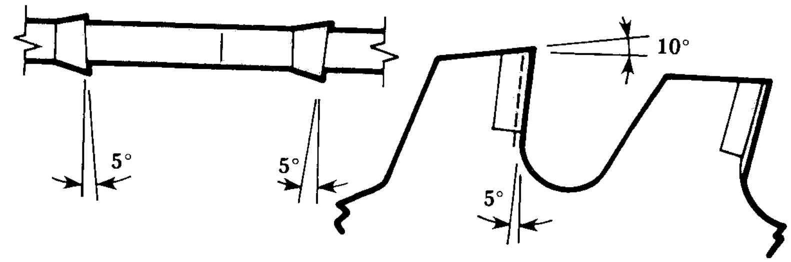
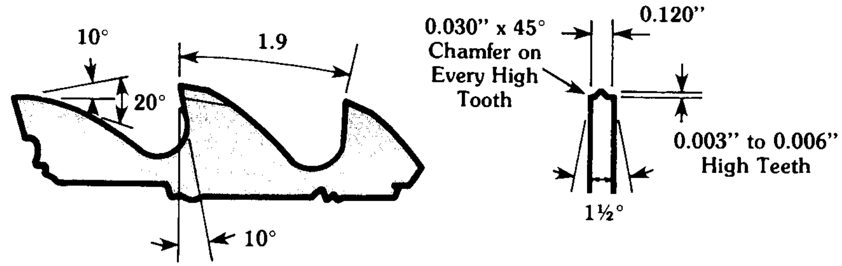


Fig. 17 — Saw for Cutting Off Magnesium Plate and Extrusions.



The alternate tooth chamfer design is also used frequently on blades larger than 18" in diameter. Recommendations for tooth spacing, speeds, set and angles for circular saws are given in Table VII, those for band saws and hacksaws in Table VIII.

TABLE VII — Data for Circular Saws for Use on Magnesium.

pitch-in teeth/inch	½-4	**face bevel**	0-5°
tooth set inches	None	**kerf**	0 080" to 0 600"
end relief angle	9-11°	**blade diameter**	8"-60"
side relief high speed only	1-1½"	**sfpm[1] high speed steel**	300-2000
clearance angle	10-30°	**sfpm[1] carbide tip**	300-10,000
rake angle	5-20°	[1]sfpm = surface feet per minute	

TABLE VIII — Data for Band Saws and Hacksaws for Use on Magnesium.

Saw Element	Band Saw	Power Hacksaw	Hand Hacksaw
pitch-in teeth/inch	4-6	2-6	12-18
tooth set inches	0 02-0 05	0 015-0 03	—
end relief angle	10-12°	—	—
clearance angle	20-30°	20-30°	20-30°

Filing

Rotary files or burrs provide excellent tools for clean-up of castings and filing of irregular surfaces. Best results are obtained from high speed steel burrs which are coarse cut with few cutting edges and deep flutes for good chip clearance. Surface hardening treatment or chrome plating give increased abrasion resistance and are recommended for longer tool life. These tools should operate at between 4500 to 7000 rpm, depending upon the burr size. The burrs shown in Figure 19 are typical of those commonly used on magnesium.

Single and double cut hand files of the coarse, bastard, and second cut types work satisfactorily on magnesium. Smooth cut files load up readily, but can produce fine finishes if light cutting pressures are used. Single cut coarse files with from 5 to 10 teeth per inch and back rake angles of approximately 10 are recommended for heavy work where an appreciable amount of metal must be removed.

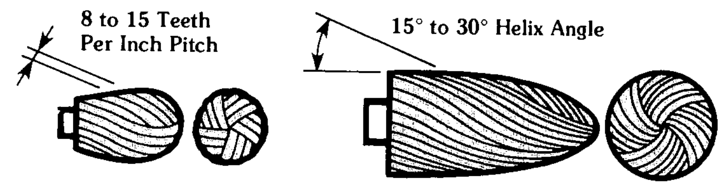


Fig. 19 — Typical rotary files for use on magnesium.

Grinding

It is usually not necessary to grind a machined surface on magnesium, since extremely fine finishes can be obtained by the machine cut. However, edge trimming, burr removal, etc. may require a grinding operation. Aluminum oxide abrasives are suggested for belt and disc grinding of magnesium. The grit size is determined by the surface finish requirements, although in the case of grinding wheels, a general rule is to use the coarsest possible grain to minimize loading of the wheels and provide rapid free cutting. Grinding is usually done dry, but with the use of an approved wet-type dust collector. The proper type of collector is an absolute necessity from the safety aspect, and is discussed in detail later under Dust Collection.

The belt or disc sander for dry grinding magnesium should be designed so that no sparking will take place should a belt or disc break and strike a bolt, nut, or any metal part that might cause a spark. The use of aluminum or plastic covers over such parts is recommended. The shield or shroud around the grinding operation also should be constructed of a non-sparking material, and should be designed for easy opening to permit removal of any caked grinding dust daily or more frequently, depending upon the amount of use.

Safety Rules for Grinding Magnesium

The following general safety precautions are strongly recommended for grinding operations:

1. Grinding equipment should be reserved for magnesium only and plainly labeled for that use. Do not grind sparking metals on the same equipment used for magnesium, unless the magnesium dust has been completely removed from the grinder and dust collector. The grinding wheel or belt must be replaced prior to changing metals.
2. Grinding chrome pickled magnesium surfaces can cause sparks; thus, dust or air-dust mixtures must not be allowed to accumulate within range of sparks.
3. Adequate supplies of an Underwriters Laboratories listed magnesium fire extinguishing powder or clean, dry, cast iron chips should be kept in plainly labeled, covered containers within reach of the operators. A hand scoop should be kept in each container.
4. Good housekeeping is essential to safe grinding of magnesium. Daily inspection and cleaning of duct between grinding wheel and collector, plus thorough cleaning of the entire dust collecting unit at least once a month, is mandatory. Magnesium dust should not be allowed to accumulate on benches, windows, pipes, etc. If there is evidence of this, the collecting system is not functioning properly.
5. Operators of grinding equipment must wear caps, smooth gloves (if used), and smooth fire retardant clothing without pockets and cuffs. The aprons or protective clothing should be easily removable and maintained free from dust.

Dust Collection

The dust produced by dry grinding magnesium must be removed immediately from the working area with a properly designed wet-type dust collection system. Proper systems precipitate the magnesium dust by a heavy spray of water, and should be so designed that dust or sludge cannot accumulate and dry out to a flammable state.

The best dust collectors are small units serving one or two grinding stands. Short, straight ducts should connect the grinder to the collector. Self-opening vents prevent collection of hydrogen during shut-down. The power supply to grinders should be interlocked with the motor driving the exhaust blower and the liquid level controller of the wet collector in such a way that improper functioning of the dust collecting system will shut down the machine it serves. A time delay switch or equivalent device should be provided on the grinder to prevent the starting of the motor drive until the wet collector is in complete operation and several changes of air have swept out any residual hydrogen. Figure 20 illustrates a dust collector for use with grinding wheel, belt, or disc stands. This design is based on one shown in Bulletin No. 48 — *Storage, Handling, and Processing of Magnesium* — issued by the National Fire Protection Association.

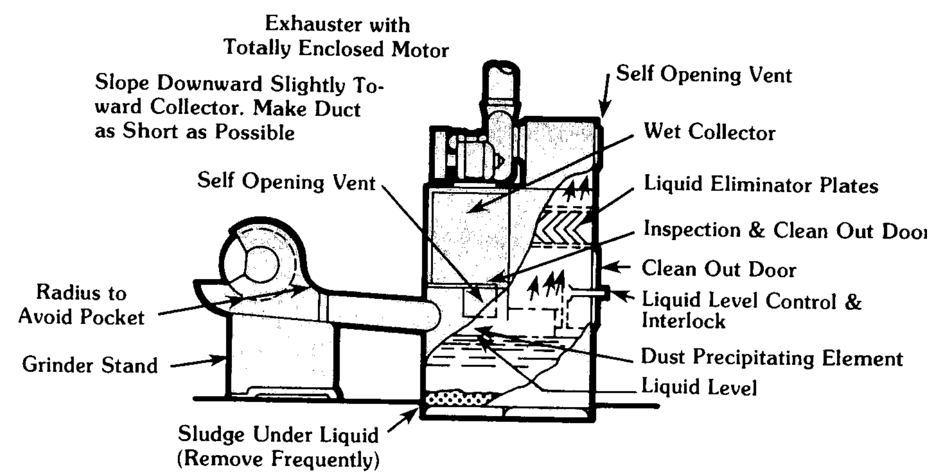


Fig. 20— Type of dust collector for use with grinding wheel, belt or disc stands.

Central collection systems which pass the dust through long, dry, or partly-dry ducts and conventional dry-type filter collectors are definitely not suitable for magnesium dust collection.

Grinding and polishing booths where the work is done on a grating as shown in Figure 21 follow the same principle of dust collection. The air in the hood flows past the work through the grating and through a water spray which removes the dust. Booths should be designed to catch a maximum of dust, keeping it off the floor and worker's clothing. It is highly desirable that the power supply to the portable grinders be interlocked in the same manner as for other dust collectors.

Grinding Sludge Disposal

Grinding dust collector sumps should be emptied of sludge daily or as often as conditions warrant. Such sludge must be disposed of as frequently as possible and never stored for long periods or allowed to become partially dry. **Partially dry sludge is extremely flammable.** Two methods of disposal are available — by controlled burning and by rendering inactive with ferrous chloride or ferric chloride solution – and both must be carried out in compliance with applicable local, state and federal regulations.

Controlled Burning

After obtaining a permit, if required under local, state or federal regulations, sludge should be burned in a segregated area at a safe distance from combustible material. The burning area may be a layer of fire brick or hard burned paving brick with sufficient slope to permit it to drain properly. The wet sludge should be spread in a layer three or four inches thick.

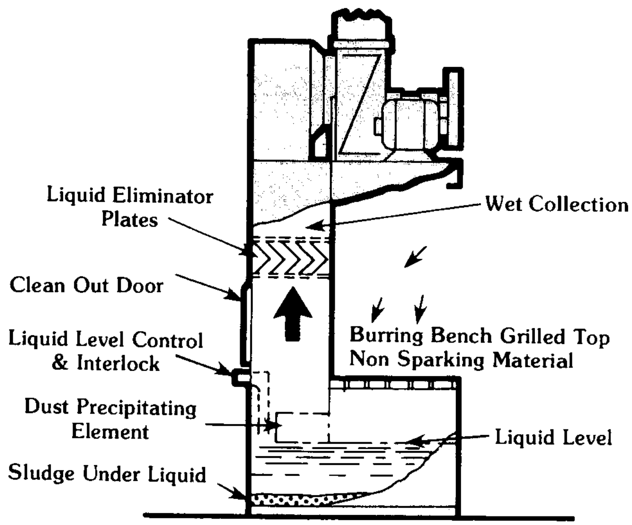


Fig. 21 — Bench type dust collector for use with portable grinding or polishing tools.

Damp magnesium sludge is more flammable than dried sludge, therefore caution must be exercised in ignition. Ordinary burnable refuse is placed over the wet grinding sludge and ignited in a safe manner. The burning refuse supplies enough heat to ignite the top surface of the sludge and the entire pile burns rapidly.

Treatment with Ferrous Chloride

After obtaining a permit, if required under local, state or federal regulations, magnesium sludge may be rendered chemically inactive and non-combustible by reacting it with a 5% solution of ferrous chloride ($FeCl_2 \cdot 2H_2O$). The reaction takes place with the evolution of hydrogen, at such a rate that the magnesium fines are changed in less than 24 hours to magnesium hydroxide and magnesium chloride to such an extent that the residue will not burn. Since hydrogen is generated by the reaction, the process should be done in an open container placed outside in such a location that natural air movement will prevent dangerous accumulation of hydrogen. Open flames and smoking should be prohibited in the immediate vicinity of the process. The amount of $FeCl_2 \cdot 2H_2O$ required to carry out the decomposition is approximately 0.6 pound for each pound of magnesium fines (dry weight). The amount of water in the sludge should be considered in determining the weight of the magnesium fines. Exact concentrations should be determined on the basis of the type of fines being handled. The cycle can be repeated daily in the same container until the amount of the brown, damp residue is such that the container should be cleaned out. To be certain of complete reaction, a sample of the residue should be heated with a Bunsen burner or oxyacetylene torch to determine if it can be ignited. While the method is simple, it should be operated under strict technical supervision to avoid landfill disposal of partially reacted magnesium.

Treatment with Ferric Chloride

Solutions of ferric chloride in water as dilute as 1% have been used to render certain types of magnesium fines non-combustible within 24 hours. The reaction can be further slowed by adding water. General handling procedures and determination of completion of the reaction process before landfill disposal of the residue are the same as used when reacting with ferrous chloride solution.

Ferric chloride is available in crystalline form ($FeCl_3 \cdot 6H_2O$) or the anhydrous form (98% $FeCl_3$). Either can be used, but the anhydrous form must be handled like an acid or caustic soda (NaOH) because of the hazard from chemical burns to the skin and eyes. Personnel handling anhydrous ferric chloride or ferric chloride solutions should wear overalls, rubber aprons, rubber gloves and chemical goggles.*

In figuring the required amounts of either ferrous chloride or ferric chloride, the water present as water of crystallization should be considered in determining the strength of the solution.

*For further information on safety and handling of ferric and ferrous chloride, consult your supplier of these materials

Polishing

Polished surfaces of any desired quality are very easily produced on magnesium. Surface irregularities are removed easily by polishing operations. High lustre surfaces on articles to be plated or used for decorative purposes can be produced by appropriate buffing. Table IX lists recommended procedures for polishing and buffing magnesium.

TABLE IX — Typical Procedures for Polishing Magnesium Alloys.

Operation	Abrasive	Type Wheel	Wheel Diam. Inches	Wheel Speed fpm	Remarks
Rough Polish	60 to 100	canvas, sheepskin or felt	6 to 12	3000 to 5000	Required only for rough surfaces such as sand castings Grease stick may be used
Medium Polish	100 to 200	built-up cloth	6 to 12	4000 to 6000	Grease stick may be used.
Dry Fine Polish	dry compound	loosely sewed buff	6 to 12	3500 to 5000	
Buffing	tripoli	loosely sewed buff 74 to 82 count cloth	10 to 14	6000 to 8000	
Coloring	dry lime	canton flannel buff	12 to 16	8000 to 12000	Minimum pressure to produce best luster.

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