LUXFER
MEL TECHNOLOGIES

DATASHEET • 254 †

Machining Magnesium

Magnesium is the lightest structural metal and exhibits excellent machinability. Some of the advantages of machining magnesium compared to other commonly used metals include:

- Low power required – approximately 55% of that required for Al
- Fast machining – employing the use of high cutting speeds, large feed rates and greater depths of cut
- Excellent surface finish – extremely fine and smooth surface achieved
- Well broken chips – due to the free-cutting qualities of magnesium
- Reduced tool wear – leading to increased tool life

To fully exploit and enjoy the advantages of machining magnesium, it is important that the unique characteristics of the metal are understood.

Cutting power and machinabilty

The mean specific cutting force (ks1.1) of magnesium is 280 N/mm^2, this is much lower than that of aluminium (approx 640 N/mm^2). The result of this means that there is a reduced load on the cutter and tool body allowing higher cutting speeds and feed rates.

The power required to remove a given amount of magnesium compared to another metal is lower. An indication of the relative power required to machine various metals is shown in Table 1. The American Iron and Steel Institute (AISI) also ranked the machinabilty of metals, using high-speed steel (HSS) tooling and taking 160 Brinell B1112 steel as the arbitrary reference point, giving it a value of 100%. Any value greater than this indicates that the material is easier to machine and conversely any value lower indicates the material is more difficult to machine.

Table 1. Relative power and comparative machinability of metals.

Metal	Relative power	AISI - B1112 machinability index (%)
Magnesium alloys	1.0	500
Aluminium alloys	1.8	300
Mild steel	6.3	50
Titanium alloys	7.6	20

Speeds, feeds and depths of cut

The potential for high speed machining of magnesium alloys is usually only limited by the stability of the component in the clamping device, chip extraction or the rotation speed or accuracy limits of the tool or machine. Some relative cutting speeds using HSS tools are given in Table 2. Cutting speeds are also dependant on the tool material. Higher speeds can be enjoyed with the use of carbide or poly-crystalline diamond (PCD) tooling.

In general, cutting speeds are between 200 – 1800 m/min with feed rates greater than 0.25 mm/rev for turning and boring operations. Face milling however, can be carried out at speeds up 3000 m/min (10000 ft/min) with feed rates between 0.05 and 0.5 mm/tooth. Depths of cut can be up to 12 mm. It should be noted that certain drilling, reaming and tapping operations are unsuitable for high speed machining.

Coarse feed rates should be employed in order to produce large chips rather than fine swarf. In general heavy feeds produce short well broken chips, medium feeds produce short partially broken chips and light feeds produce long curled chips. Well broken chips are desirable and are normally produced during the machining of magnesium.

The production of well broken chips helps with chip handling and housekeeping, this is especially beneficial when using automated or CNC machining. The production of fine swarf should be avoided due to the issues regarding flammability and the risk of ignition from the heat generated at the tool edge during cutting. Coarse chips help to take away heat from the cutting face and tool.

The surface finish of magnesium is not influenced by speed but is influenced by feed rate. If fine feeds are required for fine finishes the cutting speed should be reduced so to avoid excessive generation of heat. If fine swarf is produced, good housekeeping is essential – this is discussed in detail in the Swarf Handling section of this datasheet.

Cutting speed should also be used to control the temperature of the work piece. For example if a thin wall part is being machined, it could oscillate and rub on the tool causing friction and resulting in excess heat – the answer is therefore to slow down the cut. The use of a lower speed will reduce the generation of heat without affecting the surface finish of magnesium part. Cutting speeds for thin walled sections can be 440 m/min for roughing and 628 m/min for finishing.

The speeds recommended in this brochure are not necessarily the maximum speeds possible for certain scenarios. They should be used as a guide along with the feed rate and cutting depth parameters. The maximum speed depends on a number of factors including the design of the part, the machine tool design and material, and the stability of the part with regards the clamping setup. To avoid the generation of excess heat and reduce the risk of fire tools should never be allowed to dwell on the surface of the machined part.

Tooling

Tool ranges used during the machining of aluminium can also be used for magnesium. These give satisfactory results. However, due to the freemachining characteristics, relatively low cutting pressures and slightly lower heat capacity of magnesium, best machining practice should take the following points into consideration.

Tool material

Although HSS tooling can be used and is often employed in twist drills, taps and broaches, carbide is the preferred tooling material for most machining operations on magnesium alloys. Carbide gives a balance of economics and the ability to perform high volume production runs. It also gives a good surface finish, however, if a superior surface quality is required with long series at high production volumes, polycrystalline diamond (PCD) should be considered. PCD tools are extremely wear resistant and their use eliminates the occurrence of built-up edge (BUE) on the tool. This is due to the low adhesion tendency of PCD.

BUE is more commonly encountered while machining magnesium-aluminium alloys or when machining is carried out at very high speeds. The use of uncoated carbide tools, which allows sharper cutting edges, reduces material build up.

It is therefore recommended that uncoated carbide tools be used for machining magnesium alloys as these have a cost advantage over PCD. Although where economics allow PCD should be the material of choice.

Table 2. Comparative machinability of metals.

Metal	Turning rough m/min	Turning finish m/min	Drilling (5-10 mm drill) m/min	Milling 100 mm miller 1 mm cut m/min
Magnesium	Up to 1200	1800-2400	150-500	200-500
Aluminium	75-750	120-1200	60-400	200-300
Steel	40-200	60-300	15-30	20-25
Cast Iron	30-90	60-120	10-40	15-20

Table 3. Carbide tool ISO and ansi classifications.

Tool material	ISO 513:2004-07 classification	Properties	ANSI classification
Carbide	N01	↑ Wear resistance and cutting speed ↓ Toughness and feed rate	C3
	N10		
	N20		C2
	N30		

Use of indexable inserts mean that the tool holders used during the machining of other metals can still be employed.

The qualities of carbide tools suitable for the machining of magnesium alloys are shown in the table below. The details of both the International Standardization Organization (ISO) and the American National Standards Institute (ANSI) classifications are given.

Tool life

Studies have shown that when carbide tools are used on magnesium alloys, they have a tool life that is five to ten times that experienced during the machining of aluminium alloys.

Tool geometry

In order to take advantage of the machining characteristics of magnesium it is useful to consider recommended tool design and angles. The geometry of the tool can have a large influence on the machining process. Tool geometry can be used to aid with chip flow and clearance, reduce excessive heat generation, reduce tool build up, enable greater feed rates to be employed and improve tool life.

It is vital that tools are kept extremely sharp. This helps to avoid overheating. Dull tools can lead to problems with dimensional accuracy and tolerance, the generation of excess heat, the formation of long burnished chips, and sparking or flashing at the tool edge. It is worth checking the sharpness of the tool and sharpening if necessary if any of these phenomena start to occur.

The surfaces that come into contact with chips i.e. around the clearance angle on all tools and the flutes on drill bits used for deep hole drilling, need to be well polished and smooth. Polished chip-bearing surfaces aid the flow of chips along the tool and minimises tool build-up.

Relief and clearance angles should be as large as possible. This helps to prevent rubbing on the machined part and therefore reduces the excess heat generated by friction. The occurrence of BUE is also reduced with large relief angles. The cutting pressures encountered when machining magnesium mean that larger relief angles can be used than are usually permitted when machining other metals. Turning tools, for example, should have front clearance angles greater than 7˚.

Rake angles should be positive. The cutting pressure is affected greatly by the rake angle. For example, increasing the top rake angle from 15˚ to 25˚ can half the cutting pressure. Increasing the rake angle reduces cutting pressure but significantly impairs tool life. For maximum tool life rake angles of up to 20˚ are permitted. The rake angles on carbide tools should be smaller than those of HSS so as to prevent possible damage from chipping. For turning, a positive rake angle greater than 10˚ is recommended.

Nose radii should be kept small. However it is possible to use larger nose radii on tools for magnesium than those for other metals. Increasing nose radii permits greater feed rates to be employed for a given surface finish.

Fewer cutting edges should be employed wherever possible. For example,

- Small milling cutters and end mills should have one-third to one-half the number of teeth edges normally used for cutting steel
- Slot drills can sometimes be used instead of end mills. This helps to reduce rubbing and therefore reduces the heat generated during machining

More information is given for each individual machining operation later in this brochure.

Tooling manufacturers and suppliers

Suitable tools and indexable inserts are available from a wide range of well known tool manufacturers including Ceratizit, Sandvik/Dormer, Kennametal, SECO and Garant. Advice from the tool manufacturer and the use of catalogues and selection media should be used to aid in the selection of the most appropriate tooling for the specific job.

Clamping, distortion and tolerances

Similar to clamping aluminium, the component should be firmly clamped and supported to avoid a disfigured surface. It is preferable to clamp on heavier sections of the part to be machined. The clamping pressure should not be excessive to avoid deflection or possible permanent distortion.

Some machinists have found it of benefit to manufacture tooling clamps from non ferrous metal i.e. magnesium plate or die castings. This will assist in preventing accidental sparking from contact between tooling and work piece clamps.
The high specific heat capacity of magnesium and its good thermal conductivity means that heat is rapidly dissipated during machining. However, build up of heat in a part can occur when machining at very high speeds and feeds, where large amounts of material are removed.

The relatively high coefficient of thermal expansion of magnesium should be taken into account when close tolerances and critical dimensions are required on the finished part. The coefficients of some Luxfer MEL Technologies alloys are given in Table 4.

Table 4. Comparison of the coefficient of thermal expansion between elektron alloys.

Metal	Elektron 21	Elektron WE43	Elektron 675	Al alloys	Steel alloys
Coefficient of thermal expansion (20-100˚C)	$26.3x10^{-6}$	$26.7x10^{-6}$	$27.4x10^{-6}$	$24x10^{-6}$	$12x10^{-6}$

Cooling

For many years the machining of magnesium alloys has been carried out safely and efficiently without the need for coolants or cutting fluids. However, there may be times when further cooling of the workpiece is required, for example to:

- Minimise the possibility of distortion,
- Reduce the chance of fine chips igniting during very high speed machining,
- Prolong the life of machine tools in high volume production settings,
- Control and remove chips,
- Or even for peace of mind when using expensive modern CNC machining centres.

There are a number of ways chips can be handled and cooling can be achieved. The following sections detail some of the considerations that are important to take on board whichever route is taken.

Dry machining

In the past, machining operations performed on magnesium parts were carried out safely without the use of coolants or cutting fluids. Magnesium is an excellent material for machining dry. This is because of the low cutting pressures, free machining characteristics and the high thermal conductivity which allows heat to dissipate quickly through the part. Another factor when choosing dry machining is that, unlike machining most metals, excellent surface finishes and long tool lives can be enjoyed without the need for cutting fluid when machining magnesium.

Dry machining is usually easier, cleaner and more attractive than using coolants, which add to cost, require maintenance and cause problems with chip storage and handling. Large, well broken dry magnesium chips can have value, whereas wet and oily magnesium swarf is of no economic value.

Machining dry results in easier reclamation and recycling of magnesium swarf and also eliminates the chance of developing hydrogen gases.

In order to safely machine without a coolant, consideration should be given to tool material and design as discussed previously. The temperature of the part should be controlled by the use of machine speeds, feeds and depths of cut.

The safe efficient removal of chips is crucial when machining magnesium dry. It is essential to safely remove the chips and dust from the machining area, it is also important to extract the material safely and to isolate the collected material from the machining area. The use of slanted machine beds, bevelled pallets, chip shields and blow off chambers can help to avoid the accumulation of chips. On large transfer machines the use of conveyers can be implemented so that chips are continuously removed and collected for safe storage. Care must be exercised in designing the chip removal system, especially one that uses a conveyor, to avoid a small fire at the machining centre from becoming a big fire in the chip storage area. Compressed air should be used to blow swarf for collection. Care must be exercised when using 'compressed air to blow fines'. Aggressively using compressed air with fine swarf can result in suspending it in the air. The concern is settling on ledges and a fire in the future. Good housekeeping is hugely important in this regard. In addition, vacuum systems and extractors should be used to recover mists and dusts of magnesium particulates.

Cooling gases

In addition to chip control and removal, compressed air, argon or nitrogen gas can be used to control temperature. For example, a high pressure jet of argon gas could be used to cool the tool tip and work piece. Compressed gas cooling should be carried out in a well-designed system where fine swarf cannot be blown around the room. The benefit of both dry machining and cooling with compressed air is that the swarf and chips produced from the machining process are dry. This means storage and disposal are both safer and more economical than when oily and/or wet.

Mineral oils

Where there is a chance of chip jamming i.e. in machining operations such as tapping, reaming or deep hole drilling it is sometimes beneficial to use a coolant.

The type of oil should always be mineral oil rather than animal or vegetable oils. The use of animal or vegetable oil exacerbates any potential fire risk, since these oils can spontaneously ignite. Mineral seal oil and kerosene have been successfully used. Using oil rather than an emulsion type coolant has been shown to improve both dimensional accuracy and surface quality in certain machining operations.

Recommendations for suitable mineral oil characteristics are given below. A low viscosity is necessary to give adequate cooling. The free fatty acid content should be <0.2% in order to help prevent corrosion and inhibit the generation of hydrogen gas. Oils with high flash point and low vaporisation should be used so that the risk of fire and explosion of oil mists is reduced.

The danger with using oil is the chance of creating explosive oil mists during the machining process.

Properties of mineral oil coolants for machining magnesium

Specific gravity	0.79-0.86
Viscosity at	50˚C 1.75 ˚E
Flash point – (closed cup)	135˚C (Min)
Saponification No.	16 (Max)
Free fatty acid	0.2% (Max)

Although not as desirable as dry chips, chips that are covered in mineral oil are slightly less of a problem compared to emulsion covered chips. This is due to the fact that no water is present in the oil and as such the production of hydrogen gas is restricted. Even so, best practice would be to remove the oil from the chips before storage.

Water-miscible cutting fluids

The traditional advice regarding the use of suitable coolants was to use mineral oil. The use of water soluble oils and oil-water emulsions was not advised due to the risk of hydrogen gas development and the increased fire hazard should the chips ignite. However, developments in coolant technology have lead to a number of emulsions that now specify that they are designed to deal with any hydrogen generation, residue and splitting issues encountered when machining magnesium alloys. Even so, care should be taken if water-oil emulsions are employed. In addition to the cooling and lubricating properties of a coolant, coolants that are designed for magnesium should also have the following secondary properties:

- Low hydrogen generation – to reduce danger of explosion
- Good material compatibility – to avoid staining
- Extreme water hardness stability – to avoid the formation of insoluble soaps and resultant splitting, which can lead to staining
- Low dissolving of the Mg part – to slow the increase in water hardness

Magnesium reacts with water to form magnesium hydroxide and hydrogen gas. The evolution of hydrogen is extremely dangerous even a 4% concentration in air is explosive. Therefore, good ventilation and extraction should be present in the machine room. The recommendations for water-oil emulsions given on the following page should be followed in order minimise risks, particularly recommendations 9 and 10, these are critical to avoid a dangerous build up of gas.

$$Mg + 2\,H_2O \rightarrow Mg\,(OH)_2 + H_2$$

A possible issue with the use of an oil-water emulsion as a coolant during the machining of magnesium is due to water hardness. Water hardness mainly consists of calcium and magnesium ions. The high water solubility of magnesium means that there is a very fast build up of hardness during its machining. Most emulsions cannot handle the increase in hardness over time encountered with magnesium and this causes splitting. Splitting of a coolant involves the separation of the oil from the water resulting in the fluid becoming unusable. When the emulsion becomes unstable, bacteria will grow and cause the coolant to split quicker. A coolant specifically designed to cope with high levels of water hardness experienced when machining magnesium must be used.

Staining is also an issue when using coolants that are not specifically designed for magnesium. If a coolant not designed for the machining of magnesium is used, it is likely that a rapid discoloration and darkening of the magnesium surface will occur. To avoid staining and improve material compatibility, coolants for magnesium require the presence of effective surface inhibitors. Inhibitors are usually organic phosphorous or triazole compounds. The suitability of a coolant and its compatibility with certain magnesium alloys should always be assessed. Following testing at Luxfer MEL Technologies it is apparent that even if a coolant specifies compatibility with magnesium it may not be suitable. Stain testing should always be carried out to assess the suitability of a coolant.

The pH of the coolant is important. A low pH value could result in an acidic attack on the magnesium surface, whereas a pH greater than 9.5 may lead to excess foaming and also result in staining of the part. The pH of the fluid should be monitored to check the fluid stays within the specified pH range found on the manufacturer's datasheet. This can be checked using a pH meter or pH colour papers.

In addition to monitoring the pH, the concentration of the coolant should be monitored by using a refractometer. If the coolant requires maintenance or replacing, this should be carried out as soon as possible. Poor maintenance of a coolant can lead to poor tool life, poor surface finish, bacterial growth/odour, and attack of the metal.

In order to minimise the chance of staining, the part should not be left immersed in coolant for longer than necessary. The coolant should also be washed from the part as soon as possible.

Recommendations for water-oil Emulsions:

1. Use water with a low salt content i.e. Deionised, Reverse osmosis or Ultra filtration – distilled water – although the coolant should still be designed to deal with extreme water hardness
2. Use special cooling lubricants free from amine and boron
3. Should be alkaline, contain <3% chlorine and incorporate additions to inhibit the formation of hydrogen
4. Should incorporate organic phosphorous or triazole compounds for surface staining inhibition. (the compatibility should be tested i.e. by stain testing)
5. Large amounts should be used to flood machine during processing in order to reduce the chances of a spark
6. Modern machines require settling tanks and fine particle filters
7. Avoid high temperatures in the cooling lubricant i.e. in the cutting zone
8. Coarse feeds rates should be used to attain large chips. Small chips and fine swarf lead to a greater surface area resulting in an increase in the risk of hydrogen gas generation
9. The machining room should have explosion proof extraction/ventilation in order to avoid dangerous hydrogen – oxygen mixtures
10. Coolant recycling units and piping systems should have open reservoirs or vents to avoid the build up of hydrogen gas
11. The incorporation of hydrogen detectors in the system may be beneficial

It is worth remembering that while cutting fluids may reduce the risk of fire during machining, they can cause problems during storage and recycling of swarf. Recommendation of coolants for magnesium alloys is available on request. Some examples are Blasocut BC 37MG and Berucool 148MG, supplier details can be found in Appendix 1.

Swarf handling

The most crucial factors for safe machining are to avoid excess heat generation, especially when machining dry, and to ensure proper collection and handling of chips.

Chips should be cleared regularly during machining to avoid accumulations on floors and machines. Chip sweepings should be placed in closed drums and kept dry. Regular frequent inspection and cleaning as necessary of all areas where magnesium is machined should be conducted. Attention must be paid to ledges, roof rafters and electrical equipment. Swarf should be kept in appropriate containers as detailed below.

It is important to segregate swarf. Magnesium chips, raspings and turnings should never be mixed with chips from other types of materials. Segregation of swarf is crucial if any value is to be retained from recycling.

Fluid and chips ideally should be separated as soon as possible after machining. Use of a centrifuge, hydroclone, compaction or briquetting machine would help to reduce the danger associated with the storage and handling of wet magnesium chips. Many large companies have centrifuge, cyclonic or briquetting facilities on site.

Swarf storage

Swarf should never be stored in sacks. Examples of suitable storage equipment are type 1A2 UN approved steel drums with removable lids. Storage buildings should be non-combustible or have explosion proof venting. Outdoor storage is preferred for wet and oily chips.

Dry chips, turnings and swarf

These should be placed in dry, tightly closed, non-combustible containers such as UN approved steel drums. Safely stored, kept dry and clearly labelled. Storage should be in a dry atmosphere and in isolation from flammable materials. Chips covered in mineral oil can be stored the same way as dry chips.

Wet chips, turnings and swarf

These should be placed in covered but well ventilated non-combustible containers such as UN approved steel drums. Vents should allow hydrogen gas to escape and reduce the chance of a build up of pressure. The containers must be clearly labelled and stored in a remote location away from sources of ignition. Drums should not be stacked. The area must be well ventilated in order to avoid the build up of hydrogen gas. Covered outdoor storage is preferred, as this allows hydrogen gas to dissipate. Disposal of wet swarf should be frequent as partially dried chips may ignite spontaneously.

Best practice would be to remove the water and oil by use of a centrifuge or compacting device.

Swarf transport

Magnesium swarf is classified by the United Nations Committee of Experts on the Transport of Dangerous Goods. Transport of magnesium chips, turnings and rasping should be in UN approved drums type 1A2, steel with removable lids.

Swarf disposal and recycling

Magnesium swarf and turnings should be handled with caution and disposed of using an approved route. Luxfer MEL Technologies are committed to recycling magnesium metal containing products arising from the metals industry. Chips, swarf and turnings may be accepted for recycling in the modern purpose built facility in Manchester, UK.

The value of material will be dependent on the alloy, condition and the presence of contaminants. Further details are available in Luxfer MEL Technologies datasheet No. 258.

Fire precautions

Magnesium must be heated to its melting point before it can burn. Therefore, magnesium components will not ignite easily.

Magnesium swarf can be ignited, but simple precautions and good housekeeping can help to avoid the risk. The finer the particles of magnesium become the more easily they are ignited, so special care needs to be exercised with fine swarf. The following points should be considered in order to minimise the production of swarf and to avoid its accumulation.

1. Keep cutting tools sharp with large relief angles. Fires may be started by friction producing dust at the cutting and trailing edges of the tools
2. Use heavy feeds where possible to produce coarse chips which reduce the risk of ignition.Try to avoid fine feeds that increase heat from friction
3. Do not allow tools to dwell and rub on the work piece after the cut
4. Use compressed air to cool tool tip and work piece as well as to control swarf
5. Use appropriate mineral oil or inhibited emulsion when necessary
6. Collect turnings frequently and store in the correct way
7. Do not allow turnings to accumulate by keeping the floor and all machines dry and free from swarf
8. Keep suitable fire extinguishing media to hand (see Table 5)

Table 5. Fire extinguishers.

Recommended	Do not use
Type D fire extinguisher e.g. Met-L-X/G-1 powder	Water
DRY sand	Foam
Cast iron chips (Dry)	A, B, C fire extinguishers
Argon gas	Carbon dioxide, nitrogen

Should a fire occur, dry turnings will burn slowly and evenly but can flare up if disturbed. Fine swarf will burn more quickly and vigorously. The principle for dealing with burning magnesium swarf is to conduct the heat away and to exclude air. The way to tackle a magnesium fire is to cover and suppress rather than disturb the swarf. Blasting with extinguishing media can cause the burning swarf to spread and will greatly intensify the fire.

The presence of water will greatly intensify and accelerate combustion as it will dissociate to form oxygen and hydrogen. Hydrogen is explosive therefore; water should not be used to extinguish magnesium swarf fires.

The best extinguisher is sodium chloride extinguisher or graphite metal-base powder, both of which quickly smother flames without damaging either machinery or the unburnt swarf.
Examples are Met-L-X or G-1 powders.

Although dry sand could be used, care should be taken as water may be present from the atmosphere. If sand is to be used, it is recommended that the sand is kept in moisture proof containers.

Argon can be used if applied by a purge system so that the fire is not disturbed or aggravated by high pressure gas bursts. However, its use is limited to enclosed spaces so that a large concentration of gas over a long period of time is maintained. Magnesium will continue to burn even when covered by nitrogen gas or carbon dioxide. The latter will form toxic carbon monoxide gas. Therefore N_2 and CO_2 should not be used to extinguish magnesium fires.

Although magnesium is machined safely worldwide, some companies appear to have used the new European Directive 98/37/EC as a way to market fire suppression systems. There is actually no specific mention of magnesium in this document but the following paragraph has been highlighted.

European Directive 98/37/ EC – Mechanical Equipment – Machinery

1.5.6. Fire

Machinery must be designed and constructed to avoid all risk of fire or over heating posed by the machinery itself or by gases, liquids, dust, vapours or other substances produced or used by the machinery.

We believe that with the correct precautions and the best machining practice the risks from fire can be alleviated. However, Argon purge or powder fire suppressant systems are commercially available if required. The systems work by using a fire and explosion proof protection system. These systems use optical and thermal sensors to closely monitor the process. If triggered the protection system automatically starts the extinguishing device.

Machining operations

The speeds recommended in this brochure are based on the use of HSS tooling. Therefore, these are not necessarily the maximum speeds possible for certain scenarios. They should be used as a guide along with the feed rate and cutting depth parameters. When using carbide tools the machining speed is usually only limited by the stability of the component, chip extraction, or the rotation speed and accuracy of the machine.

Turning and boring

Turning operations present little difficulty with swarf clearance and should be carried out at the highest available speed depending on the machine tool, and the clamping and stability of the component. Although HSS tools can be employed at normal speeds, carbide tooling is the preferred choice, especially for high speed machining. If cost is not an issue, the use of PCD tooling has been shown to result in the greatest dimensional accuracy and the highest cutting speeds.

Clearance angles of 10-15° are recommended. The use of a large clearance angle helps to prevent the tool rubbing on the work piece; this ultimately reduces the heat generated by friction. Rake angles need not exceed 3-5°, but for minimum power consumption may be increased to 15-20°. The rake angle should be slightly smaller for carbide tools compared to HSS tools; this allows greater support to the cutting edge and prevents breaking or chipping of the carbide insert. The use of a small rake angle may help to reduce chatter. The side rake angle may be between 0-10° and the side clearance angle should not be less than 7-10°.

Top rake surfaces should be polished and faired into the tool body to ensure the smooth flow of turnings away from the cutting zone. A typical carbide tool form developed for high-speed turning and facing is illustrated in Figure 1.

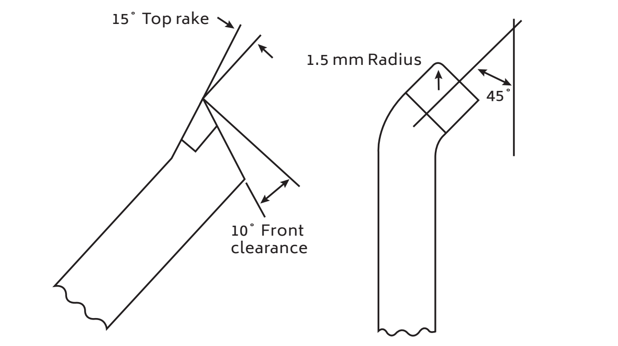

Figure 1. Typical turning tool.

A wide range of cutting speeds, feeds and depths of cut can be employed as detailed in table 6. However, very fine feeds should be avoided due to the increase in the generation of heat in the work piece. Heavier feeds are preferred and provide rapid removal of material; however, they do not result in the best surface finish. Very fine surface finishes can be easily obtained when turning magnesium alloys, but for the best surface finish, tools should be extremely sharp, have larger nose radii and the choice of a lower cutting speed and feed should be implemented. The use of PCD tools also results in a better surface finish. The depth of finishing cuts should be increased by 50-100% compared with other metals. The tool should never be allowed to dwell on the work piece after cutting. Cutting fluid is often unnecessary, but where there are difficulties with swarf removal, compressed air may be used to blow the turnings clear. If coolants are used care should be taken and the recommendations given in the coolant and swarf handling parts of this guide should be followed.

Table 6. Speeds, feeds and depths of cut for turning and boring – HSS tooling.

Operation	Speed m/min	Feed m/min	Max depth of cut (mm)
Roughing	90-180	0.75-2.50	12.5
	180-300	0.50-2.00	10.0
	300-500	0.25-1.50	7.5
	500-600	0.25-1.00	5.0
	600-1500	0.25-0.75	3.75
Finishing	90-180	0.125-0.625	2.5
	180-300	0.125-0.500	2.0
	300-500	0.075-0.375	1.25
	500-600	0.075-0.375	1.25
	600-1500	0.075-0.375	1.25

Milling

Extremely high speeds and large feed rates are possible and are encouraged during the milling of magnesium alloys; these still produce excellent surface finishes. Using coarse feed rates and high cutting speeds enables the full advantage of machining magnesium to be realised. As with turning and boring, HSS tools can be used at normal speeds, but, carbide is the tool material of choice for high speed milling operations. Indexable carbide inserts are particularly suitable for use in milling operations.

Milling cutters should have one-half to one-third the cutting edges found on conventional milling tools used on other metals such as steel. Having fewer teeth assists with chip clearance due to the increase in chip space and also reduces the frictional heat associated with a greater number of teeth rubbing on the work piece. Simple types of two and fourcutter side and face mills are illustrated in Figure 2. It is possible to successfully use slot drills instead of end mills and 2 blade fly cutters for high speed milling operations. Front and side relief angles of 7-10° and secondary clearance angles of 20° are recommended.

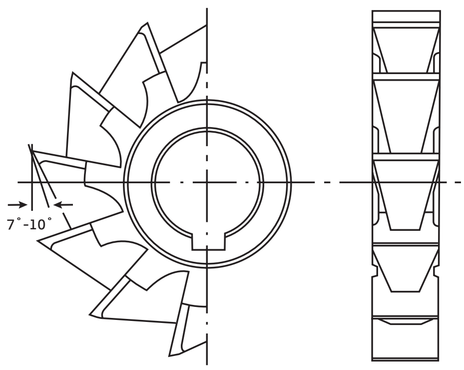

Figure 2. Side and face milling cutter.

Details of speeds, feeds and depths of cut for milling operations are given in Table 7. The speed is only restricted by the stability of the work piece, the spindle rotation speed and the accuracy of the machine. Cutting speed has little influence on the surface finish or the type of chip achieved. However, feed rate will have an effect on both surface finish and chip formation. A coarse feed rate should be used in order to produce large chips, these act as a heat sink and carry heat away from the component. The feed rate should be as great as the required surface quality will permit. The use of a coolant is usually unnecessary but if used the advice given in the coolant sections of this brochure should be taken on board.

Table 7. Speeds, feeds and depths of cut for milling magnesium.

Operation	Speed m/min	Feed m/min	Max depth of cut (mm)
Roughing	Up to 275	250-1250	Up to 12
	275-450	250-1500	Up to 10
	450-900	375-1900	Up to 5
Finishing	Up to 275	250-1250	Up to 275
	300-900	250-1750	0.13-1.3
	900-1500	250-2250	0.07-0.7
	1500-2750	250-3000	0.07-0.7

Drilling

Although magnesium can be drilled with standard twist drills, the use of specifically designed or modified drills is of great benefit. Better dimensional accuracy is often achieved with the use of a mineral oil coolant. Examples of the possible speed and feed recommendations are given in Table 8.

Table 8. Feeds and speeds for drilling magnesium.

Drill diameter (mm)	Speed m/min	Feed sheet mm/rev	Feed shallow holes mm/rev	Feed deep holes mm/min
6	100-600	0.12-0.75	0.12-0.75	0.12-0.20
13	100-600	0.25-0.75	0.40-1.00	0.30-0.50
25	100-600	0.25-0.75	0.50-1.25	0.40-0.75

Shallow holes

For drilling shallow holes i.e. where the depth is less than 4 times the drill diameter, standard drills of about 28° helix angle can be used. The point angle should be approximately 118°, with a relief angle of about 12° (see Figure 3). The chisel edge angle should be in the range 120-135°.

The cutting edges should be sharp, flutes polished and, if necessary, enlarged to aid chip clearance and avoid the build up of chips. To improve surface finish and tolerance the corners of the cutting edge should be rounded slightly.

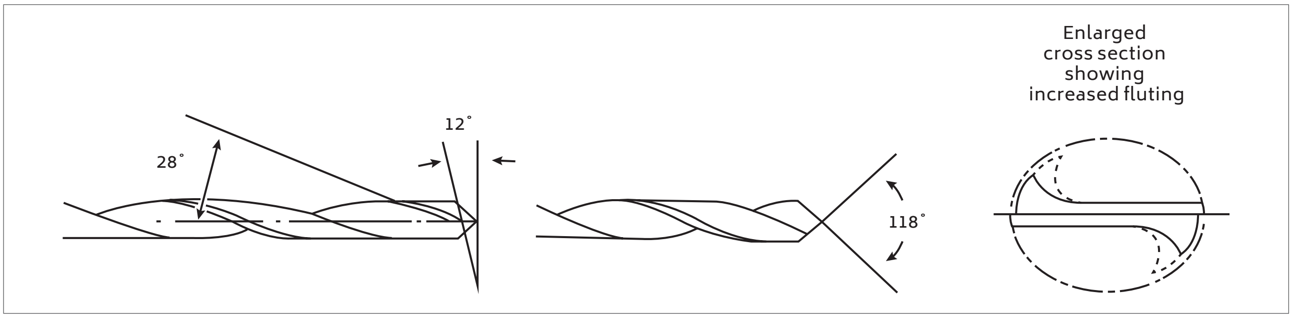

Figure 3. Twist drills for shallow holes.

Deep holes

For deep drilling the helix angle may be increased to about 47° (Figure 4) if coolant is used. Slow spiral drills with polished flutes which help facilitate the flow of chips and are better when machining without coolant. The chisel edge angles should be 135° to 150°, this minimises spiralling in the hole and also improves surface finish. Again, corners of the cutting edge should be rounded to improve surface finish.

As an alternative to a coolant, compressed air may be used for drill cooling and chip removal in deep holes. For fine drilling operations a better surface finish and greater dimensional accuracy can be achieve by using oil rather than an emulsion type coolant.

Sheet drilling

Standard twist drills used for shallow holes can be employed for the drilling of holes in magnesium sheet. However, for the most accurate holes, with a good finish and a reduction in burr formation, it is best to reduce the point angle from 118° to 60°. This limits travel of the drill on the top of the sheet, reduces the thrust, and alleviates changes in thrust following breakthrough. In order to prevent the sheet from climbing the drill after breakthrough a low helix angle of approximately 10° is recommended.

Reaming

Carbide inserts are the preferred tooling choice especially for high production runs, although steel reamers can be used, if carburised and case-hardened.

In order to increase chip space, reamers for magnesium alloys should have fewer flutes than those used for the machining of most other metals. Reamers under 25 mm diameter should have 4 or 6 flutes. Flutes can be either straight or have a negative helix. The use of negative spiral will prevent the reamer from drawing itself into the hole.

The chamfer on the reamer should be approximately 45°, with a rake angle of 7°, a primary relief of 5-8° and a secondary clearance angle of about 15-20°. The helix should be between 0 to -10°. The cutting edges should be polished and have as little land as possible see Figure 5. For fine finishes the opposing cutting edges should be spaced at 180°, however, to minimise chatter it is often beneficial to have the opposing cutting edges unequally spaced by a small amount.

It is recommended that high speeds and medium feeds are used in order to obtain the best surface finish with the greatest dimensional accuracy of the holes.

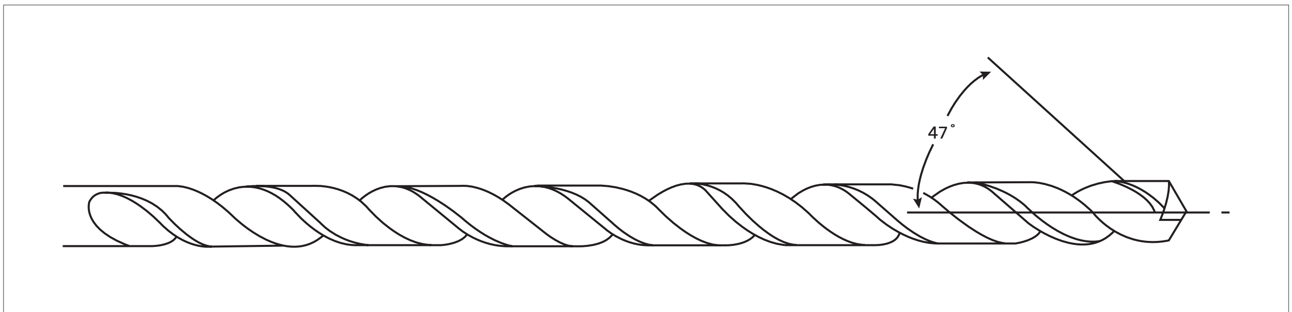

Figure 4. Twist drill for deep holes.

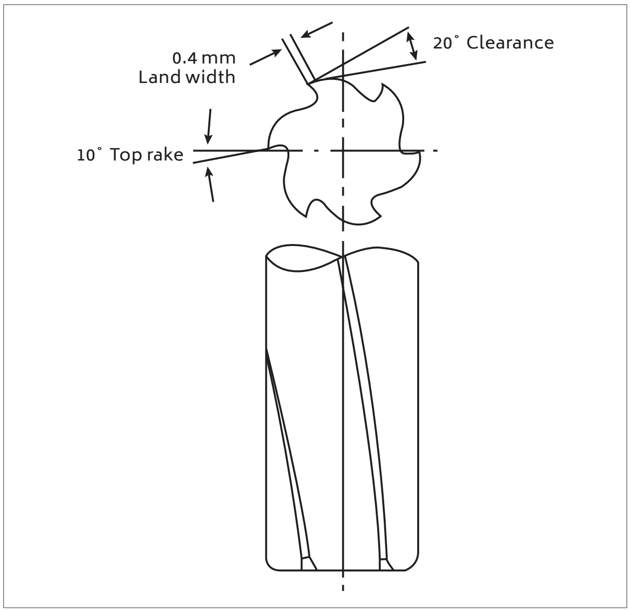

Figure 5. Reamer.

Tapping

Standard taps are suitable for small production quantities or if high tolerances are not required. For best results taps tailored to magnesium should be used. Taps should be provided with large polished flutes. HSS two flute taps with ground threads are recommended for diameters less than 4.8 mm, three flute taps for diameters up to 19 mm and four flute taps for diameters over 19 mm. Taps should be ground to be concentric with the front lead or cutting portion having a clearance of about 20°. Where there is no form relief, all lands should be hooked on both sides to give a leading top rake of about 10° for entering and about 5° for backing out where required (see Figure 6).

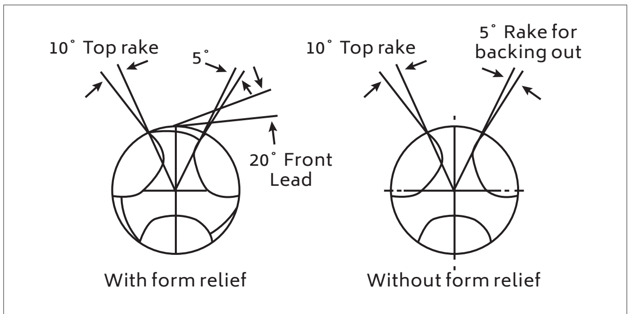

Figure 6. Taps.

When tapping holes 0.25 mm diameter and smaller the operation may be done dry. Mineral oil lubricants should be used to increase tap life, increase the accuracy of threads, improve the surface finish, or if chip jamming becomes a problem.

Threading

Dies for external threads should have the same cutting angles as the taps. The lands should be as narrow as possible to ensure clearance of the swarf. Self-opening die heads will give smooth surfaces.

End milling or countersinking

A typical tool is illustrated in Figure 7. The number of cutting edges will be 2-6.

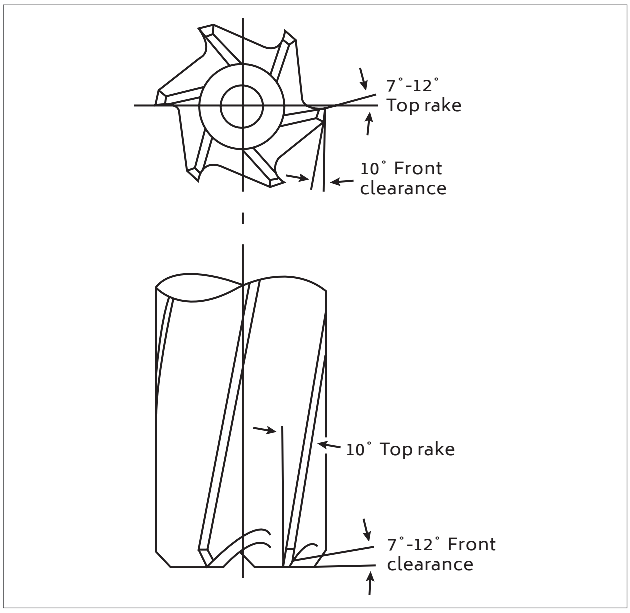

Figure 7. End milling cutter.

The cutting speeds and feeds are the same as for twist drills. A two flute slotting drill for use with magnesium is pictured in Figure 8.

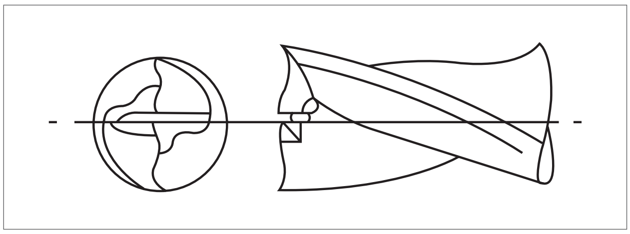

Figure 8. Two-flute slotting drill.

Rounding and broaching

These operations are quite feasible with magnesium alloys. The basic principles of sharp tool edges, small lands and generous chip clearance should be observed.

Sawing

Magnesium is easily cut with either a band or a circular saw with a power consumption of one tenth that required for steel.

For bandsaws the optimum saw size will have a tooth spacing of 5-6 mm. The set of the teeth should be 0.5-0.8 mm on either side to enable the saw to cut freely. Cutting speeds 1500-2500 m/min are generally recommended.

The pitch of the teeth on circular saws should be coarser than for bandsaws. For instance, with a saw diameter of 150-300 mm the pitch should be about 15 mm, with a diameter of 300-500 mm it should be about 15-30 mm and above 500 mm the pitch should be 30-40 mm. On large blades a precutter tooth should alternate with a finishing cutter tooth around the circumference of the blade. Cutting speeds are usually 400-2500 m/min.

Unlike aluminium, clogging of the saw teeth is not a common issue for magnesium

Filing

Coarse files with the base of the tooth rounded to prevent the swarf from jamming are recommended. Rasping wheels should be prepared along similar lines and used at speeds of 250-400 m/min.

Grinding and polishing

This is primarily a fettling operation for casting. Iron, steel or materials which spark should not be ground on wheels used for magnesium. Magnesium dust is flammable and precautions must be taken both in its production and disposal. There is, in the UK, a statutory obligation specified under the "Magnesium (Grinding of Castings and Other Articles) Special Regulations, 1946".

Grounded wet type dust collectors should be used to collect grinding dust. This system should be vented so hydrogen developed from the sludge can escape. The sludge must be removed from the system at least daily and disposed or stored in an appropriate manner.

Chemical etching

Magnesium alloy components can be reduced in thickness quite evenly by pickling in acid solution. The dissolution of metal proceeds uniformly and rapidly in sulphuric acid of 5% strength or greater. Nitric or hydrochloric acid can also be used. The part should be free of metal inserts and must be kept moving in the acid.

The process is best suited to rough castings but if tapped holes are present they should be plugged with plastic plugs.

Considerable heat is generated in the operation and frothing of the acid occurs because large volumes of hydrogen and steam are produced. Inspection should be frequent and gas traps avoided by agitation of the part.

Since the metal surface is dissolved evenly it is necessary to make the original casting large enough to allow for the chemical reduction.

Storage and handling of parts

Machined parts should be stored in dry conditions and, if condensation is likely, temporary protection should be applied. Rough castings straight from the foundry and even semi finished components need only a dip in water repellent oil. Finished work may require specialised coatings, see Luxfer MEL Technologies datasheet 256.

Discover more at
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† The information contained within is meant as a guideline only

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