HYDRO MAGNESIUM

MACHINING MAGNESIUM

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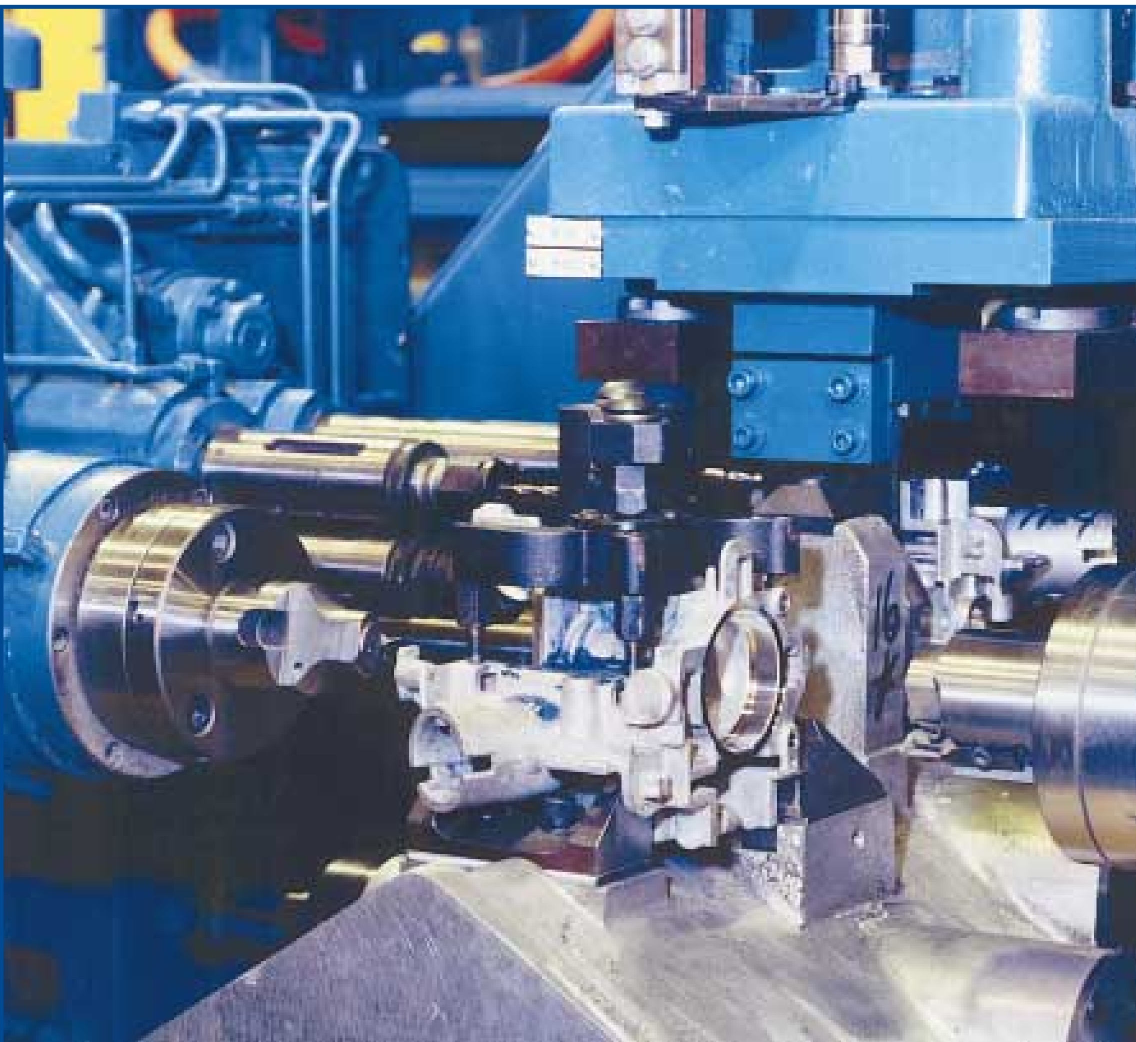


HYDRO

Magnesium Die Casting

As a supplier to the magnesium die-casting industry, Hydro Magnesium provides technical support to its customers to contribute to superior quality in the finished products.

This brochure discusses the machining of magnesium alloys on the way from cast part to finished product. Emphasis has been placed on practical tool and machining data. The discussion includes safe use of cutting fluids and handling of residuals. The information will hopefully contribute to increased awareness regarding safety during the machining of magnesium.

The data contained in this brochure is general in nature and is not intended for direct use without due consideration to each specific technical or scientific application. Hydro Magnesium accepts no liability for the use of the information, which is given in good faith, to the best of our knowledge, but without warranty.

Machining Magnesium

Preface

Although many magnesium die-castings are produced to near net shapes and do not require machining, some magnesium parts and products require one or more machining operations.

This brochure focuses on the main factors which affect the machining of magnesium:

- Material properties.
- Tools and machining data.
- Cutting fluids.
- Safety.
- Handling and storage of residuals.
- Reclaim and disposal of residuals.

Comprehensive regulations regarding the processing and handling of magnesium are issued by the authorities of various countries. Some of these are presented in the list of references (1,2,3,4).

Further technical enquiries may be directed to Hydro Magnesium at the addresses listed on the back cover.

Magnesium properties

Physical properties

Magnesium (with a density two thirds that of aluminium) is the lightest of the metals commonly used in the mass production of structural components.

In addition to its light weight, magnesium has other valuable properties, including excellent machinability, which qualify magnesium alloys as the optimal material for many applications.

The physical properties of the common magnesium die casting alloys are quite similar. The specific values for AZ91D are shown in Table 1.

Table 1. Physical properties of magnesium alloy AZ91D.

Density, 20°C	1.81 g/cm^3
Specific latent heat of fusion	370 kJ/kg
Specific heat capacity, 20°C	1.02 kJ/kg K
Thermal conductivity, 20°C	51 W/K m
Linear coefficient of expansion, 20-100°C	$26 \cdot 10^{-6}$ K^{-1}

The coefficient of thermal expansion of magnesium is slightly higher than that of aluminium, and more than twice that of steel, and should be taken into account if close tolerances are required. In some cases, it may be necessary to use low cutting speeds and slower feed rates to prevent unacceptable heating of the component.

For very close tolerance machining of some magnesium parts, stress relieving may help to ensure dimensional stability. This is considered the exception rather than the rule.

Magnesium has a relatively low modulus of elasticity, which can lead to distortion of thin parts if they are incorrectly clamped during machining.

Mechanical properties

Magnesium alloys are produced from primary metal and refined recycled metal. All the current die-casting alloys have strict limitations with regard to the content of metal impurities, especially copper, nickel and iron. The most commonly used die-casting alloys are AZ91D, AM50A and AM60B. AZ91D is an alloy with excellent castability and high strength, while AM50A and AM60B are alloys with higher ductility and fracture toughness suitable for components like intstrument panels and steering wheels. AS and AE alloys provide improved resistance to creep at elevated temperatures.

Tables 2 and 3 show the chemical composition and mechanical properties of the main magnesium die-casting alloys.

Table 2. Chemical composition of magnesium die-casting alloys (weight %)

Alloy	Al	Mn	Zn max	Si max	Cu max	Ni max	Fe max	RE	other each max
AZ91D [1]	8.3-9.7	0.15-0.50	0.35-1.0	0.10	0.030	0.002	0.005		0.02
AM60B [1]	5.5-6.5	0.24-0.6	0.22	0.10	0.010	0.002	0.005		0.02
AM50A [1]	4.4-5.4	0.26-0.6	0.22	0.10	0.010	0.002	0.004		0.02
AM20 [2]	1.6-2.6	min. 0.1	0.2	0.10	0.010	0.0012	0.005		0.02
AS21 [2]	1.8-2.6	min. 0.1	0.2	0.7-1.2	0.010	0.002	0.005		0.02
AE42 [2]	3.5-4.5	min. 0.1	0.2	0.10	0.02	0.002	0.005	2.0-3.0	0.02

1) ASTM B94-94a.

2) Recommended values.

Table 3. Mechanical properties at room temperature.[1)]

Property	Unit	AZ91	AM60	AM50	AM20	AS21	AE42
Ultimate tensile strength	MPa	250	240	230	210	220	230
Tensile yield strength (0.2%)	MPa	160	130	125	90	120	145
Fracture elongation	%	7	13	15	20	13	11
Impact strength [2)]	J	9	18	18	18	12	13

1) The mechanical properties of a die-cast part depend upon process control during casting. The values shown refer to separately die-cast test bars.

2) Charpy un-notched test bars.

Machinability

The cutting energy for machining of magnesium is lower than for other materials as illustrated by Figure 1.

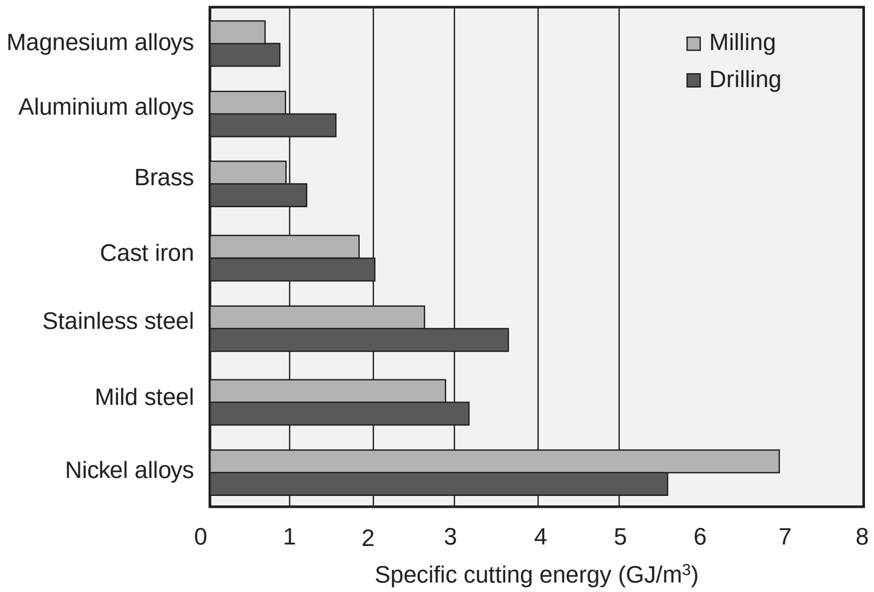


Figure 1. Values of specific power consumption (net), E_{sp}, for a variety of metals as determined for drilling and milling. The figure is based on ref. 5.

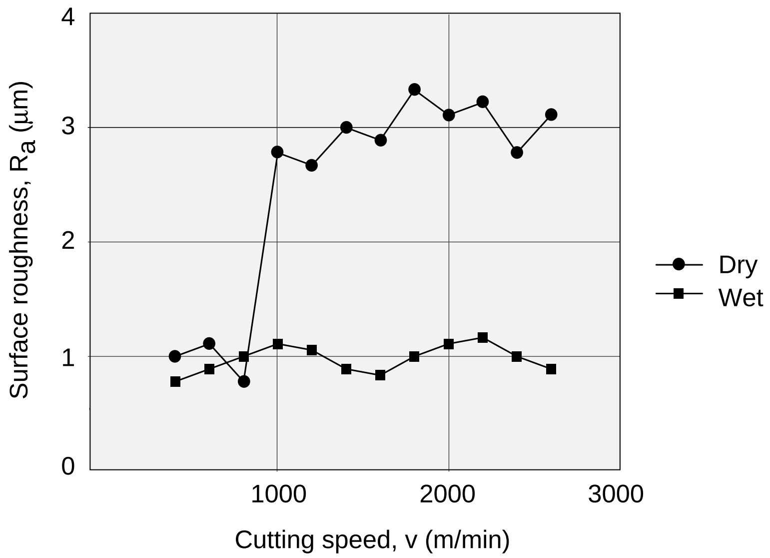
The low power requirements for machining magnesium alloys permit the use of deeper cuts and higher feed rates, and thus permit fast and efficient machining, as compared to other metals.

Magnesium alloys normally produce well-broken chips, which are easy to handle.

Material build-up may occur on carbide and high speed tools during dry machining at very high speeds (6). The build-up occurring during machining of magnesium is predominantly flank adhesion, which differs from the familiar built-up deposits on the rake face of the tool. When the build-up reaches a certain size, it comes in contact with the machined surface. Subsequently, the surface quality becomes impaired, while at the same time the force required for cutting increases.

Figure 2 shows the results of turning tests conducted on car wheels. The results show that the flank build-up problem during dry machining at high cutting speeds was eliminated by using an oil-water emulsion cutting fluid. The use of a mineral oil will also have a similar effect.

Figure 2. Surface roughness of AZ91D versus cutting speed for dry machining and machining using oil-water emulsion.



Tools and machining data

Tool materials

Carbide tools are predominantly used for the machining of magnesium alloys. Due to sharper cutting edges of uncoated tools, the problem with formation of material build-up is less when uncoated tools are used. Normally, high speed steels are only used for tools with more complex forms, e.g., twist drills, taps, broaches, etc. Polycrystalline diamond (PCD) tools should only be considered when machining long series at high production rates demanding a superior surface quality. Material build-up is not formed when PCD tools are used.

Tool design

Good results are normally obtained when magnesium alloys are machined with tools designed for machining aluminium. However, because of the low resistance to cutting and the relatively low heat capacity of magnesium, the tools should have smooth faces, sharp cutting edges, large relief angles, small rake angles, few blades (milling tools), and a geometry which ensures good chip flow during machining. Special attention should be given to the relief and clearance angles which should be as large as possible to prevent rubbing of the machined surface, which may lead to overheating and material build-up on the tool. Because of the low cutting forces required, these angles can be larger than those permitted for other metals.

A single point tool used for turning, with geometry shown in Table 4, is used as the basis for the following discussion on tool design.

Chips, rather than coils, are produced during the machining of magnesium. Hence, a large back rake angle promotes free chipping. Because the forces required for machining magnesium are low, the side rake angle can be low for maximum strength without creating a power penalty. Rake angles on carbide tools should be smaller than those on high-speed tools to reduce the possibility of tool chipping.

Digging is less likely with magnesium than with other metals, and the end relief angle should be kept large to avoid rubbing of the machined surface. Furthermore, the forces required for machining magnesium are low, and therefore, in order to prevent rubbing, a relatively large side relief angle can be permitted without reducing the strength of the cutting edge. During finishing operations, the amount of heat generated is relatively low, and the angle can consequently be lower.

Magnesium chips should be as large as practically possible in order to minimise fire hazards, and a large side cutting edge angle should be used.

The machined surface is smooth, even under poor machining conditions, and the nose radius can be kept low to prevent any possible chatter, with no subsequent reduction of smoothness.

Table 4. Typical tool design for high-speed steel tools for turning of magnesium (7,8).

Back rake angle	10 - 20°
Side rake angle	0 - 10°
End relief angle	10 - 15°
Side relief angle	10 - 15°
End cutting edge angle	15 - 45°
Side cutting edge angle	60°
Nose radius	0.5 - 1.5 mm

Machining data

General machining data is shown in Table 5. Under ordinary condtions magnesium can be machined at maximum speeds and with a feed rate and depth of cuts as great as the capacity of the machine permits.

Thread rolling is not recommended for magnesium because of its limited cold workability. However, self-threading screws can be used.

Table 5. Nominal speed, feed and cut depth for turning, drilling and milling of magnesium alloys (7,8).

Machining method	Tool material	ISO (AISI) classification	Speed m/min.	Feed mm/rev.	Depth of cut mm
Turning, rough	Carbide [1]	K30 (C2)	90 - 1500	0.25 - 2.5	13 - 4
Turning, finish		K05, K10 K20 (C3)		0.08 - 0.65	2.5 - 1.3
Drilling	High speed steel, carbide[1]	S2-S5 (M1-M3,M7) K05,K10,K30 (C2, C3)	90 - 600	0.1 - 1.3	
				mm/min.	
Milling, rough	High speed steel, carbide[1]	S2-S5 (M1-M3,M7) K05,K10,K30 (C2, C3)	275 - 900	250 - 1900	13 - 5
Milling, finish			300 - 2750	250 - 3000	2 - 0.75
Tapping	High speed steel	S2, S3 (M1, M7, M10)	20 - 50		

[1] Uncoated tools are recommended.

Cutting fluids

Traditionally, magnesium alloys were machined without using cutting fluids. Although dry machining is less common today, the low cutting forces required and the high thermal conductivity of magnesium result in a rapid dissipation of heat, which keeps the machined surface cool.

The main arguments for using cutting fluids for the machining of magnesium are as follows:

- ▶ Reduced fire risk, due to reduced temperature in the cutting zone.
- ▶ Elimination of material build-up on the tool.
- ▶ Prolonged tool life.
- ▶ Ease of chip removal.

When wet machining is selected, a mineral oil or a low hydrogen-generating oil-water emulsion should be used. Animal- and vegetable oils are not suitable for machining magnesium.

The selection and application of cutting fluids is often related to technical, safety and environmental aspects. It is therefore necessary to select an appropriate cutting fluid, in order to ensure optimal results and prevent hazardous situations.

Mineral oils

Numerous mineral oils, with relatively low viscosity, work satisfactorily with magnesium. The use of oils with low flash points is strongly discouraged. Recommended properties of mineral oils to be used for magnesium machining are given in Table 6.

Table 6. Recommended properties of mineral oil cutting fluid for machining of magnesium (7).

Property	Value
Specific gravity	0.79 - 0.86
Viscosity at 40°C, SUS	55
Flash point, minimum, °C	135
Saponification number, maximum	16
Free acid, maximum, %	0,2

Mineral oil cutting fluids have the following disadvantages:

- The machined parts must be cleaned prior to further handling.
- The working area will contain oil aerosols.
- Risk of oil-magnesium fire.

Oil-water emulsions

Water-based coolants are successfully used for the machining of magnesium (9). However, some factors must be taken into account.

Magnesium and magnesium alloys in contact with oil-water emulsions will generate hydrogen gas according to the following equation:

$$Mg + 2H_2O \longrightarrow Mg(OH)_2 + H_2$$

Mixed with air, hydrogen in the concentration range 4 to 74%, is flammable. Hence, in order to ensure safe machining operations, the accumulation of hydrogen in the machine and its surroundings must be prevented.

This is achieved by:

- Minimising chip accumulation.
- Separating chips from coolant.
- Extraction of hydrogen by proper ventilation.
- Selection of low hydrogen-generating emulsion.

Hydrogen gas sensors installed in hood extractors are recommended when machining with oil-water emulsions.

Some commercial coolants are not suitable for magnesium because of their high reactivity and short service life. Therefore, it is important that an appropriate water based cutting fluid is selected. Fluids with high pH and proper corrosion inhibitors should be used. Practical experience with selected coolants has demonstrated that hazardous concentrations of hydrogen do not occur during the machining of magnesium.

Emulsions previously used for steel or other materials may cause discolouration of magnesium.

A summary of the advantages and disadvantages of dry and wet machining are shown in Table 7.

Table 7. Comparison of dry and wet machining.

Method	Advantages	Disadvantages
Dry machining	Simplified chip handling. Easy chip reclaim. Higher recycling value.	Fire risk. Build-up edge at high cutting speeds. Reduced tool life. Complicated chip removal.
Mineral oil	Reduced chip ignition risk. Inert to magnesium. Improved tool life. High cutting speeds. Easy chip removal.	Risk of oil fire. Complicated chip reclaim. Aerosols in the atmosphere. Requires cleaning of parts.
Oil-water emulsion	Reduced chip ignition risk. Improved tool life. High cutting speeds. Easy chip removal.	Formation of hydrogen. Complicated chip reclaim.

Safety

Hazards

When machining magnesium, several safety aspects must be considered. Machine operators and others working with residual magnesium must have a good understanding of all safety aspects before machining commences.

The main hazards to be considered are:

- Fires.
- Dust explosions.
- Hydrogen evolution due to a reaction between magnesium and water.

To prevent fires and dust explosions the following general rules should be observed:

- Smoking and open flames are prohibited.
- Spark-proof tools must be used.
- Cutting operations must only be performed after thorough cleaning.
- Equipment must be adequately grounded where there is risk of dust explosions.
- Adequate fire extinguishing materials and equipment must be available in the machining area.
- Regular equipment cleaning and dust disposal (minimum once per shift).

The most important regulations related to the machining of magnesium are presented in the list of references (1, 2, 3, 4).

Personal safety

To a large extent, injuries can be avoided by using proper safety equipment. The following personal equipment is recommended:

- Flame-retardent clothing.
- Safety glasses with side shields.
- Aprons, to reduce metal dust accumulation on clothing.

Emergency showers should be located within a reasonable distance to the working area.

Safety during machining

Certain rules should be followed to prevent or minimise potential problems during machining operations:

- Keep the cutting tools sharp with adequate cutting angles.
- Use high feed rates and deep cuts to produce thick chips.
- Do not allow tools to rub against the workpiece.
- An appropriate cutting fluid must be selected for wet machining.
- The supply of coolant must be sufficient to keep the temperature in the cutting zone low.
- Hydrogen gas in the machining area should be removed with an explosion-proof extraction fan.
- The machines and surroundings should be frequently cleaned in order to minimise chip and dust accumulation.

Grinding

Grinding is no less hazardous than machining. Dust ignites readily and may give rise to dust explosions. Proper equipment and good operating routines are crucial. In addition to the safety precautions mentioned above, the following precautions must be taken:

- Grinding should be conducted well away of open flames, cutting and welding operations.
- Grinding equipment should only be used for magnesium.
- Use an appropriate wet dust collector system.
- Ensure that maintenance and cleaning routines for the wet dust collector system are adequate. Dust collectors should be cleaned regularly (minimum once per shift).
- Magnesium-water sludge should be kept under water until disposal.
- All electrical equipment in the immediate area should be explosion-proof and properly grounded to eliminate electrical discharges.
- Vacuum cleaners must not be used unless they are specifically designed and approved for use with magnesium powder and dust.

Further information regarding dust handling is given in reference 10.

Spills

The key to safety is clean working conditions. Spills of magnesium particles should be frequently cleaned up with spark-proof tools. Vacuum cleaners can be used only if they are specially designed and approved for use with magnesium. Dry particles should be stored in closed containers free from any humidity, while wet particles should be stored in vented steel containers.

Fire fighting

The following agents are recommended for extinguishing magnesium fires:

- Dry magnesium foundry flux.
- Dry, coarse, oxide-free iron chips.
- Fire extinguisher, type D.
- Dry sand.
- Inhibited graphite powder

- Extinguishing materials, in adequate quantities, must be readily available.
- Small fires are easily stopped by removing the burning particles and letting them burn on a fire-proof support, e.g. a dry steel sheet.
- Water must not be used.
- After using chloride-containing extinguishers, cleaning must take place immediately in order to prevent corrosion of structures, equipment and instruments.

Residuals

Handling and storage

Residuals from machining operations must be handled with due regard to safety and environmental considerations and according to national regulations.

Magnesium residuals should not be mixed with residuals from other materials.

Magnesium residuals from dry machining operations should be placed in closed, labelled, clean, non-combustible containers made out of steel. The containers should be stored in a dry place, in which there are no risks of water contamination.

Chips contaminated with mineral oil should be stored in the same manner as dry chips.

Magnesium chips contaminated with water or water-based coolants should be stored in wellvented steel containers. Figure 3 illustrates the effect of venting hole in the storage containers on the hydrogen concentration inside the container. The hydrogen concentration in the containers is effectively kept below the lower explosion limit of 4% with a 25 mm venting hole. It is recommended to use three venting holes with a diameter of 25 mm just below the top cover of the container. The storage area and the transport vehicle must also be properly ventilated to prevent accumulation of flammable hydrogen-air mixtures.

Prior to storage and transportation, it is important to remove as much coolant as possible from the chips. Water removal methods currently in use are filtration, centrifugal drying and compression. Figure 4 shows the effect of allowing wet chips to dry in air at ambient temperature before storage.

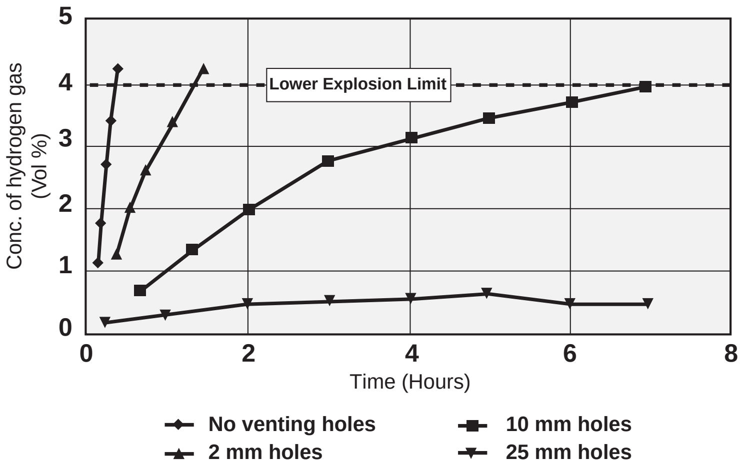


Figure 3. *Effect of venting holes in the container on the accumulation of hydrogen inside the container. The cutting fluid was destilled water with pH = 7 (11)*

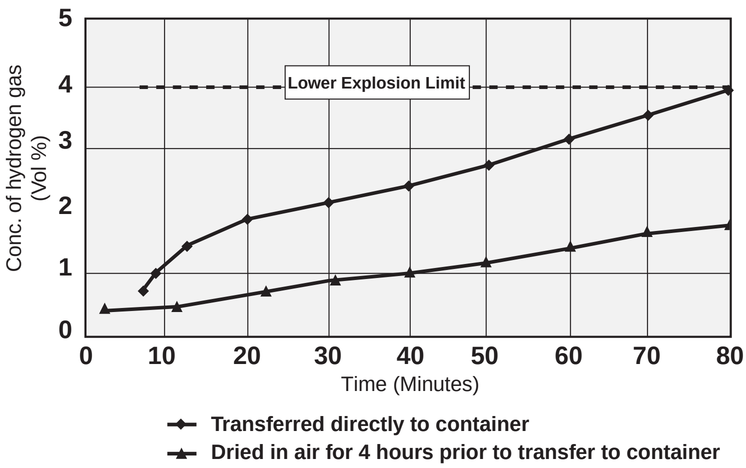


Figure 4. *Effect of leaving the chips to dry at room temperature for 4 hours prior to storage. The cutting fluid was destilled water with pH = 7. The chips were stored in a container with a 2 mm venting holes (11).*

Reclaim

Magnesium chips and fines should be regarded as valuable resources.

Some of these materials are processed into desulphurization products for the iron and steel industry.

While dry chips may be readily recycled, recycling of oily and wet chips requires special attention with regard to cleaning, emission control and safety.

Waste disposal

If reclaim of machining residuals is not economical or practical, the residuals must be disposed of in a non-hazardous manner and in compliance with local regulations.

Possible methods of disposal include:

- Dissolving in a 5% aqueous solution of ferrous chloride.
- Dissolving in sea water.
- Land filling.

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Basic elements in machining of magnesium

The machining characteristics of magnesium are excellent.

- **More metal can be removed per unit time.**
- **Surface finish is smoother.**
- **Tool life is longer.**

Prevent chip ignition by minimising the heat generated by machining.

- **Keep the cutting tools sharp.**
- **Do not allow tools to rub on the machined surface.**
- **Select a proper cutting fluid and ensure ample flow.**

Minimise safety hazards.

- **The workplace must be kept clean and free from accumulated chips.**
- **Apply an appropriate wet dust collector system.**
- **Always maintain an adequate supply of fire extinguishing agents.**
- **Do not allow hydrogen gas to accumulate during machining or storage of chips and dust.**

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