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Magnesium Alloys and its Machining: A Review

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Abstract: *From the last few years it can be easily noticeable that the liking of magnesium and its alloy has increased in many industries. The maximum interest is noticed in automobile industries because of low weight of magnesium. But in addition to this it also has many other applications which are discussed in this paper. The study of machining of magnesium is very important for researchers and industries. In this paper the main topic on machining of magnesium is introduced. Some applications and properties of magnesium is also discussed to give overview of magnesium. Some experiments on drilling, turning, milling processes are also reviewed. At the end the conclusion of this paper is given.*

***Key Words*: Magnesium Alloys, Machining, Turning , Milling , Drilling**

Introduction

Magnesium and its alloys are the lightest as compared with all other metals. It has very impressive properties. It is as light as plastic and as tough as metal. Some other properties are good machinability, high specific toughness and rigidity, weld ability and cast ability. Due to these impressive properties its liking is increasing in the industries. The main reason for its increasing usage is its light weight and high tensile strength as compared to steel and aluminum. The Fig. 1 shows the increase in number of articles which are published with the name magnesium alloys in their abstract.

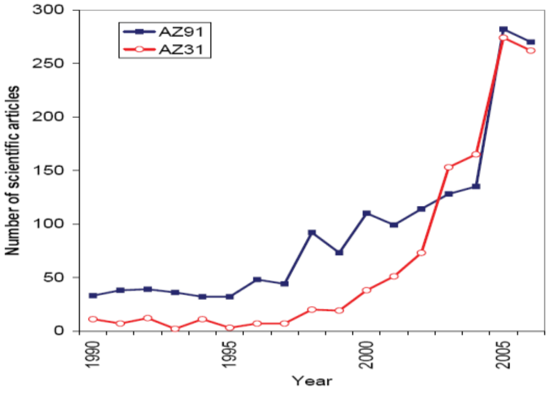
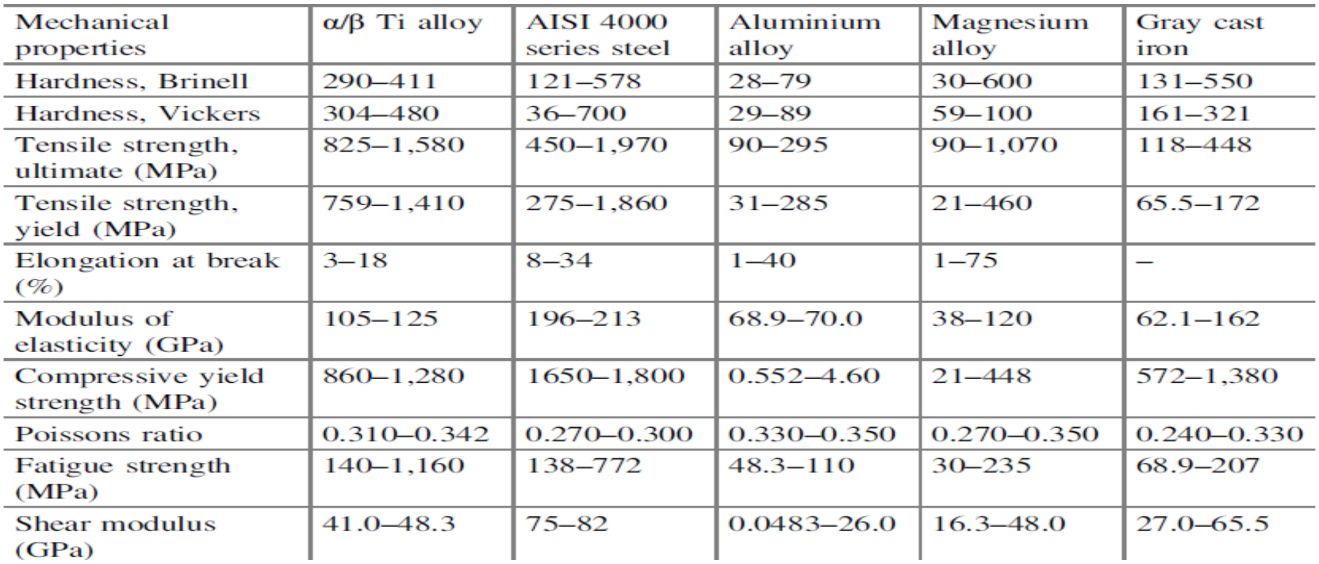


Fig1. number of articles with magnesium as abstract in recent years.

Properties

The structure of magnesium is HCP i.e. hexagonal closed packed or hexagonal crystal structure. This is the main reason that magnesium cannot be easily deformed at room temperature. The alloys formed in between the range of 340 – 510 degree Celsius. The difficulty of cold forming is the main reason that casting becomes suitable for producing magnesium pieces. The atomic number of magnesium is 12 and it is the lightest of all engineering metals, having density of 1,7g/cm3. It is two-third of that of aluminum and one-fourth of iron.

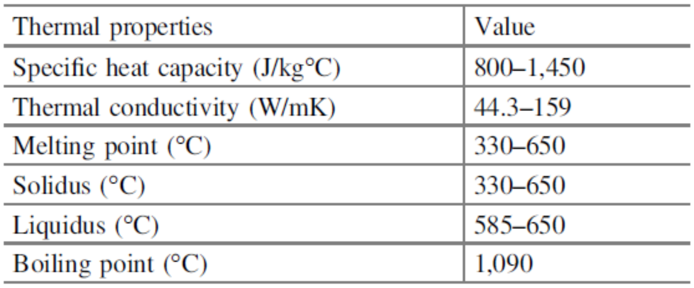
As the mechanical properties plays very crucial role in machining so Table1.shows some of the properties of magnesium and its alloys with comparison of other metals.



Mechanical properties	α/β Ti alloy	AISI 4000 series steel	Aluminium alloy	Magnesium alloy	Gray cast iron
Hardness, Brinell	290–411	121–578	28–79	30–600	131–550
Hardness, Vickers	304–480	36–700	29–89	59–100	161–321
Tensile strength, ultimate (MPa)	825–1,580	450–1,970	90–295	90–1,070	118–448
Tensile strength, yield (MPa)	759–1,410	275–1,860	31–285	21–460	65.5–172
Elongation at break (%)	3–18	8–34	1–40	1–75	–
Modulus of elasticity (GPa)	105–125	196–213	68.9–70.0	38–120	62.1–162
Compressive yield strength (MPa)	860–1,280	1650–1,800	0.552–4.60	21–448	572–1,380
Poissons ratio	0.310–0.342	0.270–0.300	0.330–0.350	0.270–0.350	0.240–0.330
Fatigue strength (MPa)	140–1,160	138–772	48.3–110	30–235	68.9–207
Shear modulus (GPa)	41.0–48.3	75–82	0.0483–26.0	16.3–48.0	27.0–65.5

Table 1showing mechanical properties of magnesium compared with other metals.

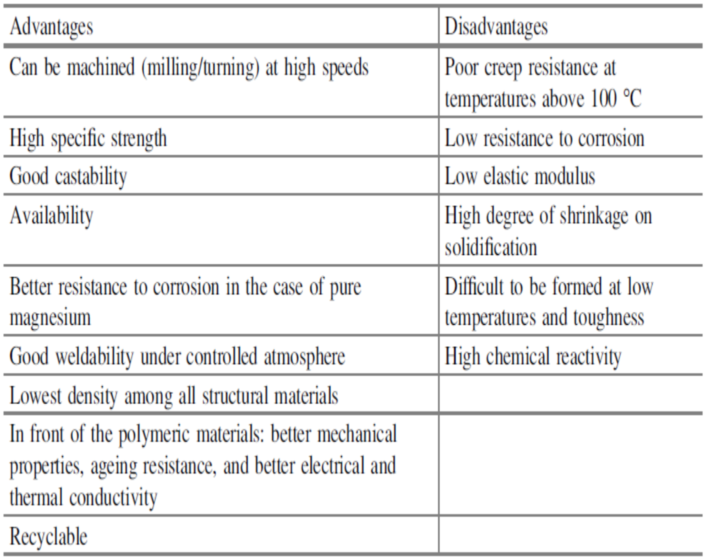
In addition to mechanical properties the properties related to temperature are very crucial as the change in temperature also effects the production as well as results of machining process. So the Table 2.shows some of the thermal properties of magnesium alloys.



Thermal properties	Value
Specific heat capacity (J/kg°C)	800–1,450
Thermal conductivity (W/mK)	44.3–159
Melting point (°C)	330–650
Solidus (°C)	330–650
Liquidus (°C)	585–650
Boiling point (°C)	1,090

Table 2 Thermal properties of magnesium

Magnesium alloys have many advantages as well as it also has some disadvantages also. Table.3 shows some of the advantages as well as disadvantages[9,15].



Advantages	Disadvantages
Can be machined (milling/turning) at high speeds	Poor creep resistance at temperatures above 100 °C
High specific strength	Low resistance to corrosion
Good castability	Low elastic modulus
Availability	High degree of shrinkage on solidification
Better resistance to corrosion in the case of pure magnesium	Difficult to be formed at low temperatures and toughness
Good weldability under controlled atmosphere	High chemical reactivity
Lowest density among all structural materials	
In front of the polymeric materials: better mechanical properties, ageing resistance, and better electrical and thermal conductivity	
Recyclable	

Table 3 Advantages and disadvantages

Applications:

To give some overview some applications of magnesium alloys are discussed below:

1. **Automotive Industry**:

The main reason for usage of magnesium in this sector is because of low density. As there is a need

To reduce the weight of automobiles to have fuel efficiency, many automobile industries are showing interest in magnesium.

As per the studies in the past most trusted automotive industry Volkswagen used magnesium in one of its car named Volkswagen Beetel. After that in addition to this many other automobile industries like Audi, BMW, Toyota, Porsche and Ford also used magnesium in some of its parts.Table 4.shows the usage of magnesium in parts of automobiles.

Part	Magnesium alloy
Wheel	AM60A and AZ81A
Pump	AZ91
Inlet	AZ91
Transmission cover	AZ91 and AZ81A
Cylinder cover	AZ91B
Gearbox	ZE41A
Suspension	ZE41A
Chassis	ZE41A
Steering wheel core	AM60A
Inner door	AM60B

Table 4 Usage of magnesium in automobile parts

2. Aeronautics/ Defense

in aeronautics is limited to the engines and transmission because of the cost factor. The main example of usage of magnesium in aeronautics is WE43 alloy of the transmissions for the MD500 and MD600 helicopters [5] and QE alloy in the nose wheel fork in the Jaguar fighter [4]. The alloy of magnesium is also used in gearboxes especially in aircrafts.

3. Medical Treatments:

The usage of magnesium is also in applications of medicals because of its low weight. Magnesium has been used in varioustransplants in humans as well as animals [19].

4. Electronic Industry:

Magnesium has also been used in electronic devices such as covers of mobile phones, cameras, mini disc players etc.

Machining of Magnesium

Firstly, the meaning of machinability is the ability of material to machine or the ease of machining a metal. Cutting forces such as power consumption and shape of chips are generally taken in defining machinability. There are some properties which makes magnesium better metal to machine as compared to other. The main properties are cutting speed, tool life, chip formation, depth of cut, cutting forces and surface finish.
Anil Chandra and Surrapa [1] influenced the geometry of the tool specially the rake angle in turning of magnesium. The cutting energy of magnesium used in magnesium machining is also very low as compared to other metals like aluminum, iron. This property of magnesium alloys the usage of deep cuts and more feed rate. The speed of cutting is also very largeas compared with other metals. The Figure 2 shows the cutting speed with comparison to other metals.

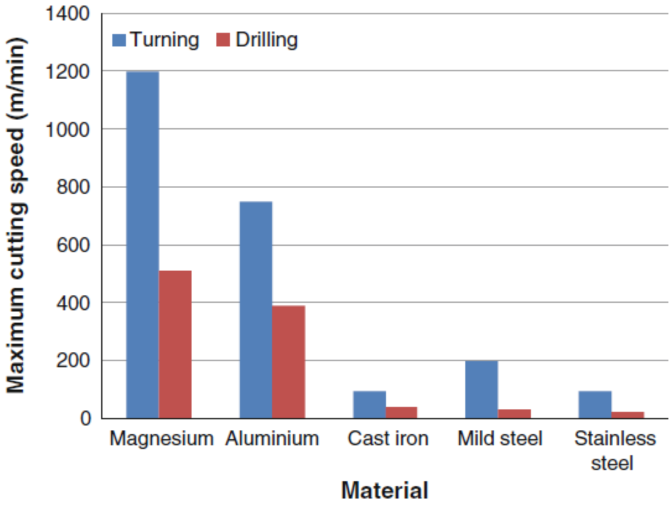


Fig2 Cutting speed with comparison to other metals

According to **Byrene et al**[3]it is possible to have cutting speed 4000-6000 m/min and feed per tooth of .6mm in milling, 1000m/min and .8mm/rev in drilling. One of the alloys of magnesium named AZ91 HP is abrasive free and has very little vulnerability to adhesion in surface of tool.

The generation of burrs is also one of the aspects to be considered during machining of magnesium. The burrs are caused by different factors such as tool geometry, tool wear, machining parameters, tool path. Moderate cutting speed is recommended in case of face milling [11].

Review of Experiments

In this article the main experiments which are performed on magnesium are reviewed. At the end of the article summary of each article is also given in form of tables. The three main processes discussed are – Turning, Milling and Drilling.

1. Turning

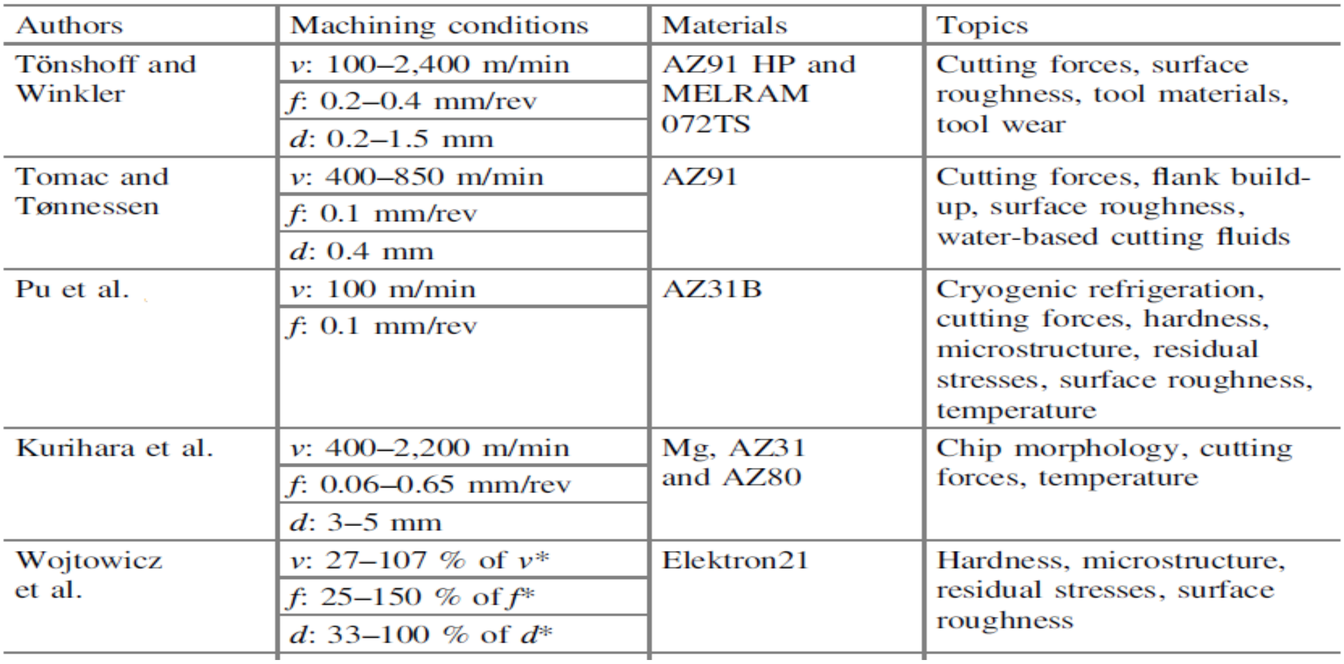
1. **Tonshoff and Winkler [20]**: They worked on magnesium alloy named AZ91 HP and studied the effect of tool coating. Mean roughness depth is used to evaluate roughness. It has been observed that tools coated with PCD gives best consequences as compared to uncoated and tools coated with TIN. The cutting speed taken is 2400m/mm; depth of cut was 1.5mm and the feed rate was .4mm/rev.

2. **Tomac and Tonnessen [16]**: They studied the use of cutting fluid based on water and concluded that it reduces the temperature and prevents building of flanks. It was also concluded that use of cutting fluids at low and medium cutting speed can give bad effects causing wear of tools and bad roughness of surface.

3. **Pu et al [13]**: he worked on turning process of AZ31 B and concludes the influence of environment. The value of surface roughness observed was .2um. This is even worst ad compared to dry machining.

4. **Wojtowicz et al [17]**: He worked on turning process of Electron21 an alloy of magnesium. He concluded that rate of feed, radius of tool nose and interaction of both are significant factor.

5. **Kurihara et al [10]**: He worked on AZ31 and AZ80 alloys with machining in dry condition by the application of thermocouple method. He concludes that by increasing cutting speed the temperature also increased and reached up to 500 degree Celsius.



Authors	Machining conditions	Materials	Topics
Tönshoff and Winkler	*v*: 100–2,400 m/min *f*: 0.2–0.4 mm/rev *d*: 0.2–1.5 mm	AZ91 HP and MELRAM 072TS	Cutting forces, surface roughness, tool materials, tool wear
Tomac and Tønnessen	*v*: 400–850 m/min *f*: 0.1 mm/rev *d*: 0.4 mm	AZ91	Cutting forces, flank build-up, surface roughness, water-based cutting fluids
Pu et al.	*v*: 100 m/min *f*: 0.1 mm/rev	AZ31B	Cryogenic refrigeration, cutting forces, hardness, microstructure, residual stresses, surface roughness, temperature
Kurihara et al.	*v*: 400–2,200 m/min *f*: 0.06–0.65 mm/rev *d*: 3–5 mm	Mg, AZ31 and AZ80	Chip morphology, cutting forces, temperature
Wojtowicz et al.	*v*: 27–107 % of *v** *f*: 25–150 % of *f** *d*: 33–100 % of *d**	Elektron21	Hardness, microstructure, residual stresses, surface roughness

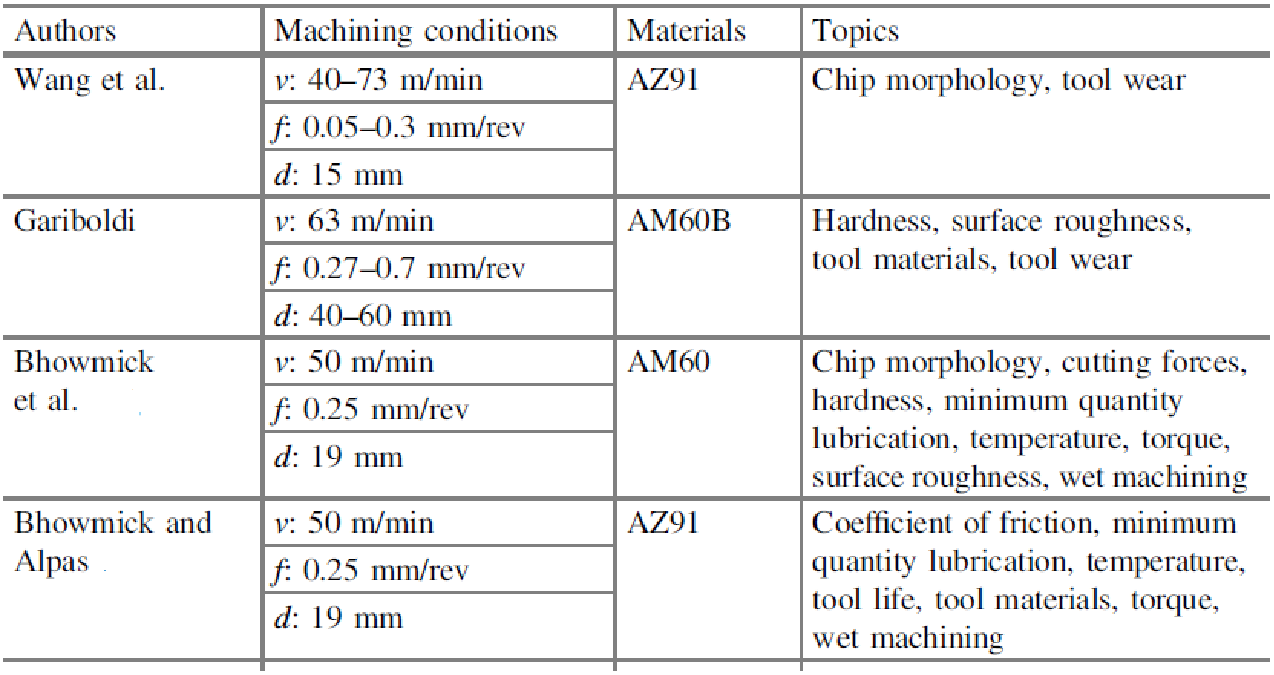
Table 5 Conclusion of work on drilling process

2. **Drilling**

1. **Wangetal [18]**: He worked on AZ91 and evaluates the tool wear in dry machining. The main mechanism identified was adhesive, abrasive and diffusion wear. They may be used to select cutting parameters.

2. **Gariboldi and Bhowmick et al [8]**: He worked on drilling process of AM60 B and AM60 and identifies the adhesion on the edge of tools. They show that using the minimum quantity of lubrication, good outcomes are found as compared to dry machining.

3. **Bhowick and Alpas [2]**: They worked on the drilling of AZ91 magnesium alloy. They shows that the usage of MQL along with diamond coated HSS tool offers result same as obtained when using HSS under flooded conditions.



Authors	Machining conditions	Materials	Topics
Wang et al.	*v*: 40–73 m/min *f*: 0.05–0.3 mm/rev *d*: 15 mm	AZ91	Chip morphology, tool wear
Gariboldi	*v*: 63 m/min *f*: 0.27–0.7 mm/rev *d*: 40–60 mm	AM60B	Hardness, surface roughness, tool materials, tool wear
Bhowmick et al.	*v*: 50 m/min *f*: 0.25 mm/rev *d*: 19 mm	AM60	Chip morphology, cutting forces, hardness, minimum quantity lubrication, temperature, torque, surface roughness, wet machining
Bhowmick and Alpas	*v*: 50 m/min *f*: 0.25 mm/rev *d*: 19 mm	AZ91	Coefficient of friction, minimum quantity lubrication, temperature, tool life, tool materials, torque, wet machining

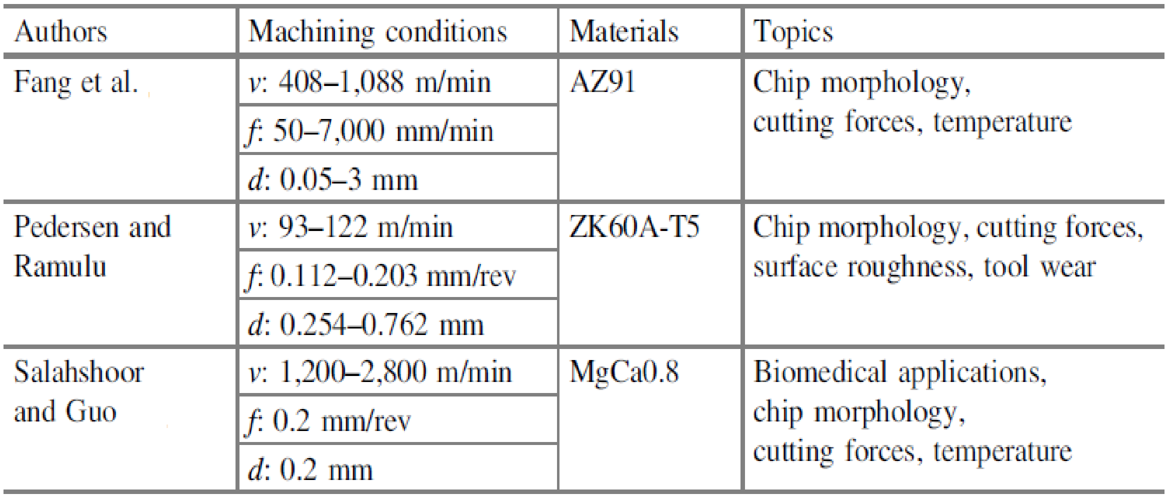
Table 6 Conclusion of work on turning process

Milling:

1. **Fang et al [6]**: He worked on the evolution of temperature in case of AZ91 alloy and shows thatthere is an increase temperature with increase in cutting speed and with decrease in chip thickness.

2. **Pedersen and Ramuler [12]**: They worked on the facing process of ZK60 A-T5 alloy matrix with 20 vol% SiC particle with 3-4 um dia. They concluded the recognition of abrasion on tool flank as themainmechanism of tool wear.

3. **Salahashoor and Gua [14]**: They studied the milling of Mg-Ca alloy with Ca% of .8% with PCD tool. They show that sparks did not occur while working with large cutting speed in the process.



Authors	Machining conditions	Materials	Topics
Fang et al.	*v*: 408–1,088 m/min	AZ91	Chip morphology, cutting forces, temperature
	f: 50–7,000 mm/min		
	d: 0.05–3 mm		
Pedersen and Ramulu	*v*: 93–122 m/min	ZK60A-T5	Chip morphology, cutting forces, surface roughness, tool wear
	f: 0.112–0.203 mm/rev		
	d: 0.254–0.762 mm		
Salahshoor and Guo	*v*: 1,200–2,800 m/min	MgCa0.8	Biomedical applications, chip morphology, cutting forces, temperature
	f: 0.2 mm/rev		
	d: 0.2 mm		

Table 7 Conclusion of work on milling process

Conclusion:

It is to be concluded that magnesium because of its impressive properties it is being used in many industries for example: automobile industry, aeronautics industry, electronic industry etc. it has good mechanical as well as thermal properties which makes its machining easy. To conclude the results of experimental review some points are given below:

1.**Turning**: It is concluded that machining conditions such as feed rate and cutting speed shows more effects on results. The usage of large cutting speed shows good outcomes but in addition to this it has the risk of increase in temperature. In addition to this the use of lubrication was also discussed and it also shows effects on the final result of the process.

2. **Drilling**: The three principle wear mechanism i.e. abrasive, adhesive and diffusion were identified. Then some results after using lubricants were also discussed.

3. **Milling**: The consequence of cutting speed on the temperature was discussed. In addition to this, the scratch on the tool flank was found as the major factor of wear in milling.

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