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Review Article

A short review on magnesium alloys in multiple domains

Yellapragada Naga Venkata SAIRAM[1,*], Tara Sasanka CHERUKURI[2], Hari Prasad KURRA[1]

[1]*Department of Mechanical Engineering, Annamalai University, Tamil Nadu, 608002, India*
[2]*Department of Mechanical Engineering, RVR &JC College of Engineering, Chowdavaram, Guntu, 522019, India*

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ABSTRACT

Magnesium is one of the most abundantly available material with good energy efficiency due to less weight. The density of magnesium is 78.5% smaller than steel and 35.6% lighter than aluminum. It is also easy to machine and can potentially be recycled. Since pure magnesium is more prone to corrosion, Magnesium and magnesium alloys are rapidly gaining more attention in multiple applications including automotive, aerospace, electronic and medical fields. The improved physical and mechanical properties of magnesium alloys make these materials as an alternative substitution to aluminum alloys and steel in automotive and aerospace structural applications. Biocompatibility and Biodegradation has given further edge to emerge magnesium alloys as an ideal alternate to the medical implant materials because of improved mechanical strengths when compared to polymeric biodegradable materials. Recent advances in 3C products (Computer, communications, and consumer electronics) also showed an uptrend in the usage of magnesium and its alloys. Based on the studies, the usage of magnesium in various domains is significantly improved in the coming years and can provide a lot of research potentials for the young researchers. Therefore, this paper reassesses the profits of magnesium and its alloy materials in various domains and summarizes the recent works in industrial applications. The potentialities, drawbacks and research scope of magnesium alloys have also been presented towards the development of commercial productsand 23.75% – 83.10%, and lead was adsorbed between 99.35% – 100%, and 72.80% – 92.00%.

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INTRODUCTION

Magnesium alloys have the minimal density of all structural metals (< 1.738 g/cm^3) increasing their usage in parts of automobiles and aircraft would increase the energy efficiency by saving weight. However, Magnesium is also the Earth's 8th most abundant product, is easy to machine, and can potentially be recycled. As a substitute to Steel and aluminium Magnesium parts are escalating now a days in automotive sector mainly [1-3]. Owing to their low density and high specific strength magnesium, based components are prominent structural materials. Consequently, they gain more acceptances in applications such as automotive,

***Corresponding author.**
*E-mail address: ynvsr@rvrjc.ac.in; sairamynv@gmail.com; sairamynv2k20@gmail.com;

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aerospace, electronics, sports equipment, etc [4]. The use of magnesium in diverse domains is depicted in Figure 1. The majority of magnesium is used for alloying with aluminium, 41% is used as a structural metal in a variety of applications, and the rest is used in iron and steel processing, electrochemical applications, and other uses.

The automotive sector is one of India's most significant contributor to economic growth, and one with a high connection with global scenarios [5]. Nonetheless, the requirement to reduce the weight of automotive components and thus reduce the production of environmentally harmful substances is nowadays a key objective for automotive producers. In recent years, the lightweight prerequisite in the automotive industry has significantly encouraged research and production of aluminum and magnesium alloys [6]. However the applicability of magnesium is not only limited to automotive application because of weight savings but also enumerous development on magnesium alloys have been evolved and discussed in next sections.

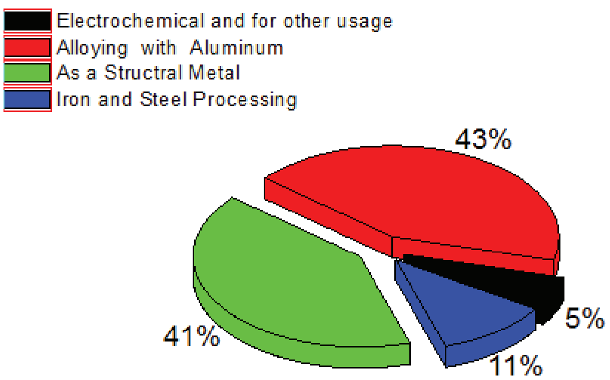

Figure 1. Magnesium Usage in different areas.

A lot of research on magnesium as implant material has been carried out in both cardiovascular and orthopedic applications [7]. Magnesium-based alloys show biodegradable, good biocompatibility and superior mechanical properties which encourage them to serve candidates as ideal biomedical materials. In particular their biodegradable ability lets patients prevent a second surgery [8]. In addition to the above-mentioned uses, magnesium is considered a good option material in view of defense and aerospace engineering the applications may include missile parts, engine mounts, control hinges etc.

Nevertheless, pure magnesium is hardly ever used, owing to its weak mechanical properties and high reactivity. This can be combined with other alloying materials to vary the properties. To make sure appropriate strength, corrosion resistance, formability magnesium is alloyed with other metals [9-11]. Moreover alloying of magnesium will always lead to improved mechanical properties because of alloying elements. Magnesium alloys are named according to ASTM coding. The detailed alloying elements and associated benefits are very much available in literature [12].

Alloys of magnesium can be divided into two categories depending on the operating cycle, namely cast alloys and wrought alloys. Many magnesium alloy systems exist such as Magnesium with aluminium, zinc, manganese, Zirconium, Rare earth elements. Of these systems, due to their ease of manufacture and availability, Mg-Al-Zn (AZ) systems are commonly used in the industry. Though the mechanical properties of wrought magnesium alloys are predominant

Table 1. Comparison of mechanical and physical properties of various materials

Material	Steel	Cast Iron	Cast Mg		Wrought Mg		CastAl		Wrought Al	
Alloy/Grade	**Galvanized**	**Class 40**	**AZ91**	**AM50**	**AZ80-T5**	**AZ31-H24**	**A380**	**A356-T6**	**6061·T6**	**5182-H24**
Density (d, g/cm^3)	7.80	7.15	1.81	1.77	1.80	1.77	2.68	2.76	2.70	2.70
Elastic Modulus (E, GPa)	210	100	45	45	45	45	71	72	69	70
Yield Strength (YS,MPa)	200	N/A	160	125	275	220	159	186	275	235
Ultimate Tensile Strength (S_t, MPa)	320	293	240	210	380	290	324	262	310	310
Elongation (e_f, %)	40	0.2	3	10	7	15	3	5	12	8
Thermal Cond. (I, W/m-K)	46	41	51	65	78	77	96	159	167	123
Thermal Exp. Coeff. (d, mm/m.K)	11.70	10.5	26	26	26	26	22	21.5	23.6	24.1
Melting Temp. (T_m, °C)	1515	1175	598	620	610	630	595	615	652	638

the applications of these wrought alloys is limited because of specific manufacturing practices such as extrusion, forging and rolled sheets. Based on the above-mentioned aspects/ facts magnesium is emerged as potential material. In subsequent sections, various applications of alloys of magnesium are discussed. Table 1 furnishes the various mechanical and physical properties of commercial cast and wrought magnesium alloys.

APPLICATIONS

Applications of Mg Alloys in Medical Field

Bone repair materials in the field of biomedical materials are shifting their gears and become a hot topic due to being an effective means of restoring human bony defects and substitution of hard tissue. For the replacement of bone tissue several biomaterials have been entrenched over a few decades. As compared to ceramic or polymeric materials the metallic materials are found suitable biomaterials due to the combination of load bearing capacity, mechanical and metallurgical behavior. Most commonly used metallic materials in surgical implants, such as austenitic stainless steel (SS), Cobalt-Chromium alloys, and pure titanium and its alloys [13].

In vivo application of implant materials such as plates, screws and pins includes removal after tissue healing by second surgery, which results in the patient's unhealthy with extra surgical costs. From the previous studies, it can be observed that the metallic materials deteriorate over a period resulting in loss of biocompatibility or bone tissue loss. Mismatched properties of natural bone and implant materials can result in stress generation and implant unstableness. Moreover, magnesium alloys are used as key structural backbone of the scaffold as in Figure 2.

Magnesium (Mg) alloys are favorably osteoconductive metallic materials, biodegradable, and being compatible thereby, it can be used in bone revamp due to their in-situ filth in the body and the ability to positively facilitate the production of new bones. In the recent past, magnesium alloys have intrigued as many biodegradable materials as possible for bone implants due to their biodegradability in the bio environment [14–16]. As their extraordinary mechanical characteristics, such as high strength and youngs modulus close to bone. In vivo studies conveys that after 6 weeks after implantation, new bone tissue developed around the alloy implant, and about 10–17 percent of the implant degraded after 9 weeks while more than 55 percent degraded after 6 months of implantation [17].

Along with the favorable impact of Ca ion on bone growth AZ91 magnesium alloy (AZ91-Ca) for the bone,

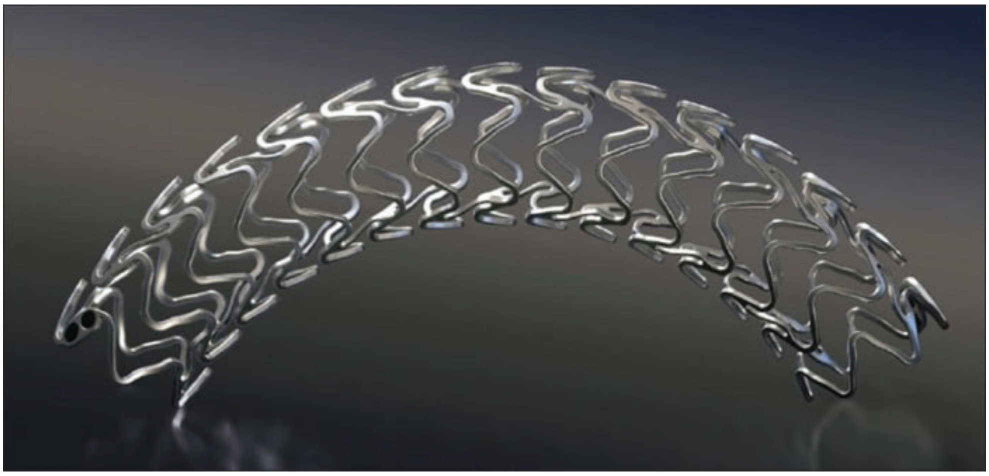

Figure 2. Magnesium alloy as the key structural backbone of the scaffold [II].

Table 2. Magnesium alloys applications in medical

Magnesium alloy	Application
Mg-Ca based alloys	Bone screws for internal fracture fixation. Biodegradable implant material [13, 16,18].
Mg-Zn based alloys	Orthopedic application, reconstruction of the intestinal tract , In vitro hemolysis and cytotoxicity assessment, potential metallic stent with anti-inflammatory function[20,27]
Mg-Sr based alloys	Skeletal applications, resorbable bone filler[8,28]
Mg-RE based alloys	Clinic as stent and screw[29-32]
Magnesium–aluminum alloy	Clinical application [8].

implant. The addition of Ca was shown to promote the corrosion resistance of the alloy AZ91 [18, 19]. Magnesium-based alloys possess a natural biodegradability due to corrosion when inserted under aqueous fluids, which is favorable for orthopedic and cardiovascular applications [20]. An attempt by Huan et.al [21] to infuse bioactive particles into a magnesium ZK30 alloy to form a MMC is a lucrative way to increase the alloy's bioactivity. Rather than simply applying existing magnesium alloys to the biomedical industry, new alloys from a nutriological and toxicological perspective should be built [22]. Magnesium alloy WE43 is used for implants,intra osceous implants , biodegradable implants and invivo applications [23-26].

Development of alloys of magnesium like pure Mg, Mg-Ca, Mg-Zn alloy, iron-based alloys like pure Fe, Fe-Mn-based alloys and other Biomaterials like pure W, pure Zn and its alloys, Ca-based and Sr-based bulk metallic glasses, etc. are extensively investigated with much focus on their mechanical properties and abrading behaviors, microstructures. Several studies have been conducted on pre-clinical, clinical trials in addition to in vitro and in vivo performance. Table 2 summarizes various magnesium alloys and their applications in biomedical field.

Applications of Mg Alloys in 3C Products

3C products means the products associated with Computer, communications, and consumer electronics i.e mainly linked to home appliances.3C products belong to high-end Mg alloy applications that have sustained rapid growth since 1990. With the increasing market demand AZ series magnesium alloys namely AZ31, AZ61,AZ80 series replacing the polymer materials like Acrylonitrile Butadiene Styrene, Polycarbonate in 3C products housing application[33]. Fig.3 depicts the outer shell of Magnesium alloy covered Digital Camera for water seal. Li .et.al [34] and Yang et.al [35] discussed the Current application of magnesium alloy in automotive industry and 3C product fields.

Figure 3. Magnesium alloy covered Digital Camera [III].

Various plastics are known to be a significant competitive factor for magnesium alloys. Nevertheless, magnesium alloys have three key advantages compared to plastics: heat dissipation, electromagnetic and radio frequency shielding, and metal feeling in a quality sense. Such factors have made magnesium an desirable material for developing new portable personal computers, video cameras, mobile phones , portable data terminals, and other items for electrical, electronic, and telecommunication [36].

Aviation Applications

Usage of new materials and emerging technologies has increased more than 80 per cent of all aerospace developments. Magnesium alloys are prominent materials in aerospace field as they are used to produce important mechanical components of aircraft, missiles, space crafts and satellites to reduce the weight of the parts. Thereby minimizing the fuel consumption rate which ultimately leads to improved engine efficiency [37]. But Mg alloys possess poor creep and wear resistance properties when compare with regular, materials such as Alloys of aluminum and steels. To counter these composite materials are developed by adding secondary phase particles or fibre additions to Mg alloys were proposed by various researchers [38-40].

Many applications of modern technologies are backgrounded by Rare Earth Elements (REEs) that creating interest to young engineers and researchers. Much of the latest REE-containing alloys work relates to Mg alloy systems. Since for past few decades Rare earth- Mg based alloys have been broadly used eye-catching combination in aerospace sector [41].In overall aircraft weight 22% was contributed by Landing gear and cabin interior if the researchers concentrate on this area weight savings have been significantly reduced. This establishes it as a significant area for weight savings. Latest alloys of magnesium replace aluminum alloy components as these offer up to 30% mass reduction, which gives encouragement to designers and engineers. In upcoming decade forged magnesium parts are likely to be used in high temperature applications. Materials like Mg-Zr, AS41 is used whereas transmission components like gearbox casings WE43 magnesium alloy is used [42]. The weight distribution of aircraft is depicted in

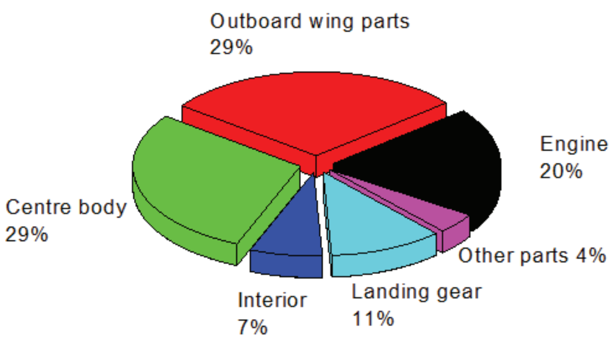

Figure 4. Mass Distribution of Air craft.

Figure 4 based on numerous studies. A key function of 58 percentage is played by the centre body and outboard wing sections. Engines (20%), landing gears (11%) and interior and miscellaneous parts make up the remaining 11%.

Applications of Mg Alloys in Automotive Sector

Magnesium alloys for the reduction of carbon dioxide emissions

Global developments are pushing the automotive industry to produce smaller, environmentally friendlier, cleaner and with economical benefit cars [45]. The leading car manufacturers concentrate on reducing car weight and lowering exhaust emissions as a result of regulatory and customer requirements for healthier, cleaner vehicles [46]. Since carbon dioxide emissions are directly proportionate to fuel utilization, car mass has become the significant criteria for determining design efficiency [47]. At the same time customer, perception for vehicle quality is increasing day after day. Therefore, Research is shifting gears towards these factors by enhancing the power train and aerodynamic designs, usage of alternative fuels weight reduction methodologies. Out of all effortless and most cost-effective solution is weight diminution of a vehicle by alternative materials [48]. Weight reduction has the benefit of reduction of greenhouse emissions and more importantly, it saves fuel consumption.

In automotive industry, most of the castings are made up of cast iron and steel but because of engine weight considerations researchers are interested toward alternative materials like aluminium and magnesium. Over the past 10 years, aluminum use has increased more than 80 per cent. From many years, alloys of aluminium are used in automobile members such as car body, cylinder heads and pistons etc. But Magnesium is a robust weight saving option which has density 1/3rd less than aluminum, 3/4th than zinc, and 4/5th lighter than steel. Now a days one of the chief weight saving option is magnesium as its density is 78.5% smaller than steel and 35.6% lighter than aluminum [49]. The weight distribution of aircraft is depicted in Figure 5 based on numerous studies. The majority of mass distribution in various automobile parts is carried out by the power train and body weight (both 58%), with the remaining parts such as interiors (10%), chassis (27%) and others accounting for the remainder (5 percent). In contrast with many competing materials magnesium has wide scope in automotive industry.

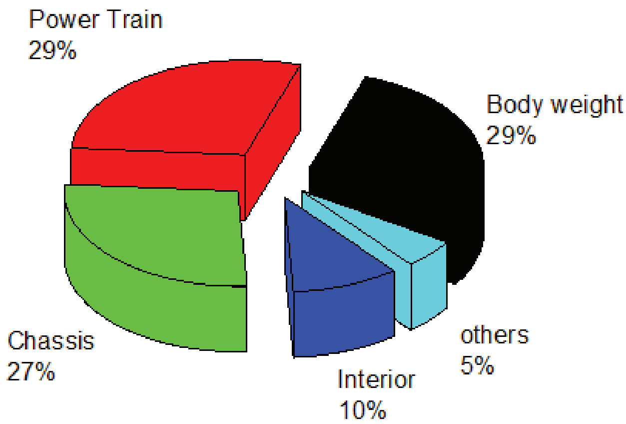

Figure 5. Vehicle Mass Distribution [47].

Magnesium alloys in various automotive components

Hyundai and Kia Motors Corporation (HKMC) use Magnesium AZ31 alloy for various interior components such as seat frame, steering wheel base, control column housing, lock assembly, driver air-bag housing, etc . From Fig.5 body weight is around 29% and can be reduced as much as possible. There are wide variety of opportunities for researchers to conduct experiments and surveys on the usage of magnesium material in interior, exterior and seat frames. The elements of the chassis are extremely individual and exhibit different behaviors among which wheels are characteristics first structures to be substituted by Mg [51]. Table 3 and Table 4 furnishes the utilization of magnesium alloys in various a components of automobile and its usage by various popular automotive companies.

Magnesium alloys are used in many leading firms such as Range rover and Land rover. To build the front-end carrier range rover velar is using magnesium alloys whereas

Table 3. Magnesium alloys applications for automotive components [52].

Engine and parts Transmission	Chassis components	Body components	Interior parts
Engine block	Rod wheels	Cast components	Steering wheel cores
Gear box	Suspension arms	Inner bolt lid section	Seat components
Intake manifold	Engine cradle	Cast door inner	Instrument panel
Crankcase	Rear support	Radiator support	Steering column components
Cylinder head cover	Tailgate (AM50)		Brake and clutch pedal
Oil pump housing			Air bag retainer
Oil pump			Door inner (AM50)

Table 4. Magnesium alloy components used by various companies [53]

Company	Part	Model	Alloy
Ford	Clutch Housing	Ranger	AZ91B
	Steering Column	Aerostar	AZ91D
	Transfer Case	Bronco	AZ91D
General Motors	Valve cover , Air Cleaner , Clutch Housing	Corvette	AZ91HP
	Clutch pedal, brake pedal, steering column brackets	Worlds mobile, Pontiac, Buick	AZ91D
Daimler-Benz	Seat frames	500 SL	AM20/50
Alfa-Romeo	Miscellaneous components (45Kg)	GTV	AZ91B
Porsche AG	Wheels (7.44 kg each)	944 Turbo	AZ91D

magnesium cross beam that supports the instrument panel is integrated in the Land rover. The pressure die cast magnesium alloy in the jaguar-F style range offers a weight saving as compared to earlier models.

Out of all automotive components power train is the most important component recent works are going on power trains, which are targeted on fewer fuel emissions, the weight reduction etc. But components of power trains must be built to resist elevated temperatures and magnesium by itself cannot meet the necessary conditions [54-56]. Several studies has been performed on AZ91D, AZ91E alloys by researchers to enhance the mechanical and tribological behaviour of magnesium alloy so that it can further used for wide range of applications [57-60].

CONCLUSIONS

Though Magnesium is not a new material, the magnesium usage in sixties and seventies is limited because of production hurdles. The circumstances have changed now and given the young researchers plenty of opportunities to work in various domains. This paper reviewed the usage of magnesium materials and alloys in biomedical, 3C products, aerospace and automotive areas. Magnesium has Lightweight and better formability so that it can accommodate all kinds of room temperature applications. Several research innovative methods have also been identified to work with magnesium at elevated temperatures particularly to suit in Automotive and Aerospace applications. The magnesium usage in these areas is growing exponentially and expected to continue the same trend in the coming days also. Out of all magnesium alloys, AZ91 series alloys are playing a vital role in various domains of research. However, the researchers should come up on new strategies to make magnesium components with commercial viability.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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I. Figure 2. **Source:** https://www.medicaldesignbriefs.com/component/content/article/mdb/features/articles/27329

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