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Analysis of Effect of Alloying Magnesium by Powder Metallurgy on Mechanical Properties: Review

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ABSTRACT

This paper reviews the use of powder metallurgy technique that is the less complicated technique in the fabrication of magnesium (Mg) based alloys as well as the analysis regarding the mechanical properties of Mg-based alloy and the impact of parameters and the materials that used in reinforcement of magnesium product.

Key words: Alloying magnesium, Metallurgy, Mechanical properties

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INTRODUCTION

Mg is considered as the lightest of the elements that could be used in structural applications, in comparison to common titanium, aluminium, and iron alloys [1]. Mg's lightness attribute is the primary reason for its appeal in a variety of clinical and industrial applications that require light-weight structures. Recent breakthroughs and research on Mg alloys are discussed. Tertiary or binary Mg alloys including Zn, Al, Zr, Mn, Ca, and rare earth (RE) elements receive special study [2]. The impact of various alloying elements on mechanical, micro-structural and corrosion properties of the magnesium alloys has been studied. Alloying changes the microstructure of the material, resulting in strengthening mechanisms that enhance the mechanical characteristics and ductility of pure Mg [3]. Mg improves the malleability of iron and mechanical characteristics of aluminium when employed as an alloying element in metallic materials.

Magnesium alloy

Mg is the lightest one of the structural metals; in weight it can be compared to plastics and in strength and toughness can be compared to a metal which is durable and have a long life [5]. It also has a yield strength, low elastic modulus, and capacity of deformation, as well as a poor and sluggish ageing responses and poor corrosion and creep resistance. Because of such characteristics, Mg and its alloys are becoming more used in the manufacturing business market [6].

Pure magnesium shows variety of good mechanical properties but with this have some weaknesses so to overcome the weaknesses of pure magnesium it is alloyed by mixing different elements to have the desired mechanical properties. Different element is added to magnesium to get desired mechanical properties; this process of mixing of element to parent material is known as alloying. Because of its hexagonal crystal structure, Mg alloys have exceptional stiffness and specific strength, as well as dimensional stability. Different elements are used for alloying magnesium to obtain different properties [7].

Mg and its alloys have got much attention in recent times as a result of its potential to replace heaver alloys with equal strengths and lighter in weight, hence become potential materiel automobile, sports, aeronautical and biomaterials applications [8].

Mg and its alloys are different from other biomaterials by having physical and mechanical qualities that are compatible with human bone. Their elastic and densities modulus are relatively similar, eliminating elastic incompatibilities between bones and implants [9].

Nomenclature of magnesium alloys

Mg alloys are classed and recognized by 2 capital alphabets succeeded by a number, based on the American Society of Testing Materials (ASTM). The alphabets define the major alloying element, the first letter is utilized for the element which has highest concentration and second letter defines the second highest concentration percentage. The numbers define the amount of major alloying elements; first number stands for weight percentage related to first element followed by the second number defining the weight regarding the second element percentage, for example: AZ91D here the magnesium alloy contains 9 % aluminium and 1 % zinc by weight (Table 1) [10].

Table 1: Nomenclature of magnesium alloys.

ASTM code	Alloying element
A	Aluminum
B	Bismuth
C	Calcium
D	Cadmium
E	Rare earth
F	Iron
G	Magnesium
H	Thorium
K	Zirconium
L	Lithium
M	Manganese
N	Nickel
P	Lead
Q	Silver
R	Chromium
S	Silicone
T	Tin
W	Yttrium
Y	Antimony
Z	Zinc

Powder metallurgy of magnesium

Powder metallurgy can be defined as one of the most significant approaches for improving Mg mechanical characteristics, and it might also improve corrosion resistance because of the induced plastic deformation [11]. The strong affinity of Mg for oxygen influences it's processing, resulting in producing a thermo-dynamically stable corrosion product layer on the surface of Mg powder particles. Throughout PM processing, the formed layer significantly reduces the operations of diffusion that are necessary for the densification of the material [12].

Due to the fact that Mg has a high affinity for oxygen, handling Mg specimens and powders, along with subsequent sintering, requires using protective environment (typically nitrogen or argon) [13]. Also, the porosity related to the processed bulk material is commonly seen as one of the drawbacks of PM processing procedures [14]. The porous bio-compatible material, on the other hand, may be easily integrated into tissue and degrades at a precise rate, providing one of the tools for modifying the features of PM processed material for the bio-medical applications [15]. In addition, the functional porosity regarding PM processed Mg-based implant could enable implant deterioration and primary fixation through allowing bone cells to infiltrate (osseointegration) the degrading implant. Mg corrosion products produced throughout implant biodegradation promote bone osteoconductiveness [16]. Porosity changes have an impact on the resistance to corrosions and the course of corrosion attack inside material volume [17]. Because a larger metal surface area is under the exposure of corrosion environment, extremely porous materials corrode quickly [18].

Powder metallurgy process

To make the green compact, it entails combining the matrix material in powder form and pressing it in a powder compaction die, after that, the green compact sintered in a controlled environment in order to increase its strength through diffusion bonding [19]. The next are the steps in the powder metallurgy process:

Blending of powders

It is a critical procedure. The distribution of matrix and reinforcement materials has an important impact on characteristics of PM products. As a result, achieving a uniform distribution of powders is critical. Powders are ball milled in planetary ball mills for a suitable amount of time (2–24 hours) to ensure optimal mixing [20].

Compaction of blended powder

Green compact can be defined as the process of compacting mixed powders in a die at high pressure for consolidating the powders. Compaction pressure has an important impact on the density and other characteristics of PM components. To achieve the required porosity in the material, the compaction pressure might be adjusted [21].

Sintering

The resultant green compact is frequently heated in a regulated atmosphere following powder compaction to aid the process of the diffusion between reinforcement and the particles of the powder. Also, hot extrusion has been used on occasion. Diffusion occurs rapidly at high temperatures, and metal fills the pores through the diffusion. The characteristics regarding the sintered PM components highly depend on the temperature degree at which they are sintered and the duration that they are held at that degree. The impact of several parameters of the PM on mechanical properties, such as sintering temperature, sintering time, compaction pressure, and powder and size, is investigated in the following section [22].

Review on published researches about Mg alloy powder metallurgy

Table 2 summarizes the results of published researches on Mg-based alloys with the use of the PM technique over the last ten years.

Table 2: Some of published researches on magnesium based alloys prepared by powder metallurgy.

Author and year	Alloys	Results
Hu, et al. [22]	Mg–Mn-Zn	It has strong compression and bending resistance, as well as the mechanical qualities needed for a human bone plate.
Ercetin, et al. [23]	Mg5Sn4Zn (TZ54)	The TZ54 alloy has the potential to be a machinable, alternative biomedical material.
Ravi Kumar, [24]	Magnesium (AZ91D)/Graphite/Tungsten Carbide Hybrid Composites	The research's Mg hybrid composites have great hardness, strength, and wear resistance.
Li, et al. [25]	ZK60 Mg alloys reinforced by Nano-diamond (ND) particles	Enhanced tension compression, composite's high strength, thermal mismatch strengthening, texture strengthening and Orowan strengthening, according to theoretical research.
Ondřej Hilšer, et al. [26]	AZ61	Improved the microstructure related to a hot extruded alloy, the maximum tensile and elongation of 21.4%.
Matej Brezina, et al. [27]	Pure Magnesium	Hot pressed alloy has higher strength and micro – hardness than Cold compacted materials; the electrochemical properties were much improved.
Amal, et al, [28]	Porous Mg-Zn-Ca	With a larger CaH2 level, the higher the roughness
Rashad, et al. [29]	Mg–Cu–Al	The increase in the content of the aluminum resulted in an increase in the value of the Vickers hardness, 0.20% yield strength, ultimate strength and decrease in failure strain.
Harrell, et al. [30]	Al-Mg-Sc	The Mg-O/N dispersion and precipitate strengthening contributions are the most significant for UFG and FG materials, respectively.
Zhou, et al. [31]	AZ91	The optimal sintering temperature under vacuum hot-pressing is 550°C; relative density may reach 98.3%. EDS and SEM analysis reveal that the alloy's sintering microstructure is made up of two phases: beta-Mg17Al12 and alpha-Mg solid solution. More alpha distributed on the grain boundary and increases alloy's hardness through 2nd-phase strength.
Liao, et al, [32]	Mg–Al–Mn–Ca	The corrosion resistance regarding Mg alloys could be considerably increased (spinning water atomization process).
Burke, et al. [33]	AZ31	The material had weak tensile characteristics, with maximal tensile strength of 32MPa.

Mechanical characteristics of Mg alloy that has been prepared by powder metallurgy

Tensile strength, compressive strength, and hardness are all affected by the characteristics of the powder metallurgy, such as the type of reinforcement material, its size and shape, the pressure at which it is compacted, and the temperature and time at which it is sintered [34].

Micro hardness

Mechanical hardness test is critical in evaluating mechanical characteristics that are related to metallic materials since hardness values may be used to estimate the material's wear resistance, along with the approximate values of the flow tension and ductility, amongst other significant qualities [35]. The material's resistance to indentation is specified as its hardness. In the material sciences, hardness has been specified as the material's capability to withstand permanent deformations, which are proportionate to the atoms' bonding strength. Microhardness procedures are utilized for testing practically any sort of material, including ceramics, metals, and composites [36]. Table 3 summarizes a review of published researches on the microhardness of numerous magnesium alloys that have been produced through powder metallurgy.

Table 3: Some of published researches of micro hardness of Mg–based alloy prepared by powder metallurgy.

Author & year	Alloy	Results of microhardness
Senthil, et al. [37]	Al-Mg based composite incorporated with MoS2	The Mg-6% Al-4% MoS2 composite has more Micro Vickers hardness in comparison with the pure Al
Alias, et al. [38]	Mg samples with aluminium (Al) composition variation	The values of the micro-hardness have been raised as well at 20wt.% and 50wt.% aluminum contents.
Victor, et al. [39]	magnesium alloy (AZ61) reinforced with alumina and Molybdenum Disulphide	Mg powder using 2 wt% MoS2 and 2 wt% Al2O3 yielded the highest hardness values.
Kavimani, et al. [40]	AZ31 alloy is homogeneously reinforced with reduced graphene oxide (r-GO) nanosheets	Adding 0.4wt% r-GO increased hardness and also resulted in an 84% corrosion inhibition efficiency.
Satish, et al. [41]	pure Mg metal powder with aluminum oxide and silicon carbide	The addition of alumina particles and silicon carbide to Mg metal matrix composites enhanced the composites' micro hardness.
Turan et al. [42]	Mg matrix composite that has been reinforced with fullerene	Adding fullerene to pure Mg increases its hardness.
Ghasali, et al. [43]	Magnesium-Boron carbide metal matrix composite	Mechanical testing revealed increased bending strength and microhardness (Vickers test).
Jingyuan, et al. [44]	Mg – Zn	The micro hardness HV value consistently rises as the Zn content rises.
Ponappa, et al. [45]	Pure Mg and Mg alloy (AZ91D) reinforced with Y2O3 particles	The enhanced hardness as a result of the higher yttria reinforcement.
Chang, et al. [46]	Mg-Al-Zn Alloy coated with Plasma Electrolytic Oxide	As coating time was increased, the microhardness increased. The coating layer with the highest microhardness and deepest thickness.

Diametral tensile (Compressive test)

Diametral tensile strength testing has been created to look at brittle materials that have no or little plastic deformation. A cylindrical specimen is compressed in diametral plane, perpendicular to longitudinal axis, in this test [47]. It has also been indicated that it is a procedure that may be used with powder processed materials [48]. A complex geometrical shape isn't necessary in this approach, as it is in the tensile test, yet a simple circular disk is adequate to carry out the test [49]. According to diametral tensile strength has a direct relationship with compressive strength, elastic modulus, fatigue and hardness [50]. Table 4 summarizes a review of published research on diametral tensile strength tests of numerous Mg alloys made via powder metallurgy.

Table 4: Some of published researches on diametral tensile (compression) strength of Mg – based alloy prepared by powder metallurgy.

Author & year	Alloy	Results of Dimetral tensile (compressive) strength
Suliman, et al. [50]	Mg-Zn-Mn-Sr composites	with addition of alloying elements improve micro-hardness and compressive strength significantly
Irhayyim, et al. [51]	hybrid Al matrix composite that has been reinforced by nano MgO and graphite	Diametral compressive strength and micro-hardness were both increased by increasing the weight fraction of MgO NPs.
Kumar, et al, [52]	magnesium based Metal, Matrix Composites (MMCs)	The inclusion of hard ceramic particles boosts hardness and strength while reducing ductility.
Kayhan, et al, [53]	AZ91D Mg alloy	There is an increase in the discs' relative densities with increased diametral tensile strength and Vickers micro-hardness values.

Sankaranarayanan, et al. [54]	syntactic composite foams that are based upon the magnesium matrix and hollow fly ash cenosphere particles	tension and compression strength qualities were retained or slightly improved.
Tun, et al. [55]	Mg/ZrO2 and Mg/(ZrO2 + Cu) hybrid composite	Higher micro- and macro-hardness, compressive strengths and tensile strengths.
Liao, et al. [32]	Mg–Al–Mn–Ca magnesium Alloy	The SWAPed alloy have greater mechanical qualities.
Mann, et al. [56]	Al–Cu–Mg	The swaged P/M system has considerably better concomitant tensile characteristics.
Hao, et al. [57]	porous AZ91 magnesium Alloy	Porous AZ 91 Mg alloy has significant possibilities in energy absorbing applications, according to compression mechanical tests.

CONCLUSION

This review presented the possibility of fabrication different types of magnesium alloy and composite by powder metallurgy technique and the characteristics of Mg may be enhanced by alloying. The mechanical characteristics of Magnesium can be reinforced with alloying with other metals, ceramics and rare earth materials. Microhardness and diametral tensile compressive strength of magnesium alloy prepared by powder metallurgy can be enhanced by alloying and they are affected by amount of compacting pressure and sintering temperature.

Powder metallurgy is the easiest and less complicated technique for fabrication of different types of magnesium alloy.

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