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RESEARCH ARTICLE

Importance and Effects of Yttrium on Magnesium Based Alloys – A Comprehensive Review

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Abstract

Background: Magnesium (Mg) is regarded as the most accessible element in the Earth crust and possess low structural density with increased specific strength. Selective Laser Melting (SLM) is considered as a more dependable method of creating Mg-based products. In SLM, build orientation affects mechanical properties, causing ductility to increase and tensile strength to decrease. **Objectives:** To improve the mechanical properties and increase the tensile strength and yield strength China low activation martensitic (CLAM) steels different yttrium (Y) contents are utilized. **Methods:** A fabrication of reinforced composites namely Al-Zn or Fly Ash or SiC is carried out by Stir Casting Route using Vortex Method. Powder metallurgy route is employed for preparing Al-Zr relied metal matrix composites. **Findings:** CLAM has good tensile strength and yield strength, when compared to the other alloys in mechanical properties. A comprehensive analysis is carried out about the impacts of different Y additions over the Mg based alloys and the resulting texture, microstructure and tensile properties beneath different processes are analysed in this paper. **Novelty:** CLAM is utilized to enhance the tensile strength and the analogization amid the alloy proportions which shows that the Y-CLAM possesses better tensile and yield strength of 550 Mpa compared to the existing methods.

Keywords: Magnesium (Mg); Yttrium (Y); Tensile Strength and Yield Strength (YS); CLAM; Mechanical properties

1 Introduction

Looking at the past decades, due to the implementation of stringent environment protocols, the necessity for lightweight, cost-effective and better performance materials has been increasing, in order to reduce the impacts of greenhouse gas emissions. Normally, the Conscious Mg, which is one among the composites acts as a better solution, for fulfilling the above stated factors[1]. For improving the mechanical properties of Mg, in terms of Robustness and ductility, for extending a use of Mg in industrial uses like Aircrafts, Automotive products, etc., many researches have been carried out. Moreover, in olden days, a strength of the Mg composite is improved with an aid of texture, refinement and precipitation hardening, also based on which a new Mg alloy, that involves 300∼500 Mpa. The choice of alloy elements, which greatly influences the mechanical, corrosion and microstructural properties of Mg composite, has gained high attention during recent years. In consideration with Mg, it possesses increased formation rate, but incorporates complexities namely reduced strength, toxic ions, and rapid corrosion produced by Aluminium or heavy metal elements, which develops as the foremost disadvantages, which has to be eradicated once before the employment of Mg in various applications[(2)]. Further, developments have been made in the Mg composites, for achieving cost-effectiveness and to obtain high strength Mg without rare earthed materials. Moreover, for introducing improved alloying designs namely Mg-Tin, Mg-Zinc and Mg-Calcium, many researches were carried out, which further improves the strength of the composite. As there exists large gap amid the conventional Mg rare earthed alloys and the rare earth free Mg alloys, a novel solute clustering method is recommended. Moreover, the introduction of Bio-degradable alloys, highly aids in clinical fields, since it incorporates increased bio-compatibility. Still, the very fast degradation rate, does not assist in certain applications, but it performs better compared to hyperactive Mg[(3)]. Besides, as a commercial practice, the Zinc alloy is combined with the Mg alloy, so as to improve the compatibility of the composite. In the world today, Zinc is considered as the fourth metal, once after Iron, Aluminium and Copper. By the year 2018, the global demand for Zinc got increased to a range of 13.77 Mt, which lead to the global increase in the zinc supply to about 13.4 Mt. Moreover, to meet the global consumption, a significant quantity of zinc is recycled and the resulting secondary zinc is computed in the range of 20 to 40%, with respect to the consumption[(4)]. Moreover, the addition of Zinc with other composites like Mg-Zn-Al and Mg-Zn-Zr alloys have attained high significance. In[(5)], hardening effect is formed using Mg2Zn11 particles, which is generated by the lower Mg contents of ZneMg binary alloys, with the aid of dispersion strengthening. Moreover, the previous researches only focuses on the biodegradable behaviours of ZneMg and describes about the correlations amid the mechanical properties and the microstructures. Therefore, there is a necessity to better understand the Mge-Zn alloys strengthening mechanism.

In the formation of high performance composites, without any change in the shape of the samples, the techniques like SDP (Severe Plastic Deformation) and ECAP (Equal Channel Angular Pressing) aids in preparing bulk UFG (Ultrafine Grained) metallic materials. Based on the comparative analysis, it is identified that the ECAP and HPT (High Pressure Torsion) are another two matured methods, apart from SDP methods. Besides, these two techniques have the capability to enforce increased shear strain, which further helps in forming the UFG metal with increased strength. However, there exists issues with respect to the deformation characteristics, which makes it unsuitable for certain industrial applications[(6)]. The Mg-Zn relied alloys has wide range of solidification temperature range that results in high hot tearing susceptibility, also limits the employment of it in practical applications. Therefore, the use of Y along with Mg-Zn enhances the Hot Tearing Susceptibility (HTS) and the solidification path concerned are investigated thoroughly.

However, due to increase in the quantity of eutectic liquid, the HTS decreases with increase in alloying contents. Moreover, it is disclosed that the addition of Y brings great influence over the HTS of Mg-Zn-Zr alloys. In consideration with permanent mould castings, even a little addition of Y brings great reduction in HTS. This further has high impact on the solidification path at terminal period. Moreover, high Y addition, produces solidus temperature for multi-component system, which then reduces the solidification path that further reduces the terminal freezing range. In this paper, an investigation is carried out regarding the impacts of different Yttrium additives over the Mg-Zn alloy combinations[(7)]. In addition, an analogization is carried out amid the different Fabrication techniques and the Processing approaches, also the compositions of the additives employed, to identify an optimal technique.

In recent times, the developments brought in Mg alloy have enhanced its usage in many fields namely automotive, aerospace and in sports. In consideration with the medical filed, the Mg alloy not only possess the strength, weight and density equivalent to human bone, but also improves the growth of the human bone. Nevertheless, Mg also includes drawbacks with respect to the corrosion resistance and the mechanical properties. This review mainly gives out the following contributions.

1. An investigation is carried out about the impacts of Y addition with the Mg-Zn alloy combinations and its influence over the mechanical and microstructure properties of Mg-Y-Zn alloys.

2. Then, different fabrication techniques used in manufacturing Mg-Zn alloy with RE alloys are analysed.

3. Further, the different processing approaches and the alloy combinations used in manufacturing Mg-Zn and Y alloys are discussed.

4. In addition, the different additive proportions and the alloys, employed in Mg-Zn-Y alloy manufacturing are discussed.

5. Moreover, the recommendations for future works that assists in signifying the importance of Y alloy with other alloys are also discussed.

2 Methodology

2.1 Fabrication Techniques Used in Manufacturing Magnesium Based Alloys

Generally, for manufacturing alloys, Fabrication techniques plays the main role and certain fabrication techniques employed in manufacturing Mg based alloys are explained as follows.

2.1.1 Vortex Method (VM) with Stir Casting Route

Ceramic reinforced Aluminum matrix composite have become increasingly important in structural applications. In this work, a fabrication of reinforced composites namely Al-Zn or Fly Ash or SiC is carried out by Stir Casting Route using Vortex Method. Here, an evaluation of microstructural characterization and mechanical behaviour of an AlZn alloy that has fly ash and SiC as reinforcements is conducted. First, 53 m-sized composites made of SiC and fly ash are manufactured in weight percentages ranging from 0 to 10 wt%. Further, the prepared composites are characterized with the aid of scanning electron microscope, optical microscope, tensile testing machine and EBSD (Electron back scattered diffraction). From the characterization, it is concluded that the particulates are found to be uniformly distributed all through the matrix and provides improved hardness, as well as tensile properties namely yield strength and ultimate tensile. Moreover, the EBSD analysis shows that the AlZn alloy with SiC and Fly ash, are found to be finer than matrix alloy. However, as inert gasses are used at the time of casting, it is impossible to identify the oxygen peaks, as well as other contaminations[8].

2.1.2 Ingot Metallurgy Method (IMM)

In[9], In this investigation, hydride-dehydrated (HDH) titanium powder, Al powder and master alloy powders served as the raw materials for the synthesis of a PM Ti-5Al-5Mo-5V-3Cr (wt.%) alloy. The target nominal composition raw powders are blended for 1.5 hours at 60 rpm in a V-shaped blender. Then about 250 °C and under an uniaxial pressure of 400 MPa in Ai, 500 g powder mixture is warm-pressed into a cylindrical green powder compact with a diameter of 56 mm and a relative density of 83%. The modified hot-pressing method is used to solidify the powder compact. The inside wall of the mould is sprayed with graphite cream before the hot pressing to act as a lubricant. The green compact is quickly heated in an induction coil to the desired temperature of between 1250 and 1300 °C while being shielded by an argon environment. This was followed by a hot-pressing operation under uniaxial pressure. Ingot produced through conventional double vacuum arc remelting (VAR) and casting. An analytical technique known as chemical titrimetry is used to determine the precise chemical compositions of the as-consolidated PM and as-cast IM Ti-5553 alloys. Table 1 illustrates the outcomes. It is evident that the oxygen content 0.08% in the IM alloy and 0.36% in the PM alloy represented the primary difference in the chemical composition of the two alloys. Additionally, compared to the as-consolidated PM alloy, the as-cast IM alloy exhibited slightly higher alloying element content.

Table 1. Chemical composition of the two alloys

Alloys	Al	Mo	V	Cr	O	Ti
PM	4.99	4.94	4.93	2.90	0.36	Bal.
IM	5.14	5.02	5.03	3.10	0.08	Bal.

Ion milling is used to create the TEM samples for the TEM observation and twin-jet electron polishing is used to create the TEM samples for the TEM observation of the IM alloy.

2.1.3 Comparative Analysis

For investigating different fabrication methods used in Mg based alloys, a comparative analysis is carried out. Table 2 depicts a different Fabrication methods used in the manufacturing of Mg alloys.

Table 2. Fabrication techniques used in Mg alloy fabrication

Sl. No	Methodology	Ref.	Advantages	Disadvantages
1.	In this paper, a Powder metallurgy route is used for preparing the Al-Zirconia relied metal matrix composites, which are doped with Yttria.	[10]	The increase in Yttria doping leads to high stability in the zirconia crystallographic phase.	Proper analyzation has to be carried out for identifying its thermal stability.

Continued on next page

Table 2 continued

2.	In this paper, a Dieless drawing technique is employed to fabricate Mg alloy micro tubes.	(11)	Provides good corrosion performance. Exhibits outstanding mechanical properties.	Only local corrosion performance is enhanced.
3.	Using hydrothermal treatment, at about 80 degree Celsius, the Yttrium citrate is synthesized with the aid of citric acid and Freshly precipitated Yttrium hydroxide.	(12)	Homogeneous particles and forced hydrolysis are attained.	However, frequent heating of yttrium citrate leads to carbon-dioxide emission.
4.	For improving a corrosion resistance of Mg alloys, an effective surface treatment known as MAO (Micro Arc Oxidation) is introduced.	(13)	As it possess double layered structure, the MAO highly assists in enhancing the corrosion properties of Mg.	The high internal stress beneath the coating produced by the corrosion products, leads to undesired peeling off.
5.	Using diffusion alloying technique, the AZ91D Mg alloy with zinc oxide is manufactured.	(14)	Significantly less pre-treatment of the magnesium alloy matrix. Less complexity in storage and the transport of diffusion source.	As more vacancies exist in the MgO alloy, less Zn atoms moves into the Mg alloy.
6.	In this work, using hydrothermal technique, the clinochrysolite like Mg silicate nanotubes are Fabricated.	(15)	Substantially improves the anti-corrosion property. Exhibits excellent water repellency.	However, the corrosion in Mg alloy combines with the strong alkalization existing in local area, due to an OH produced.

Figure 1 illustrates a comparative analysis amid different fabrication techniques employed in manufacturing Mg alloys.

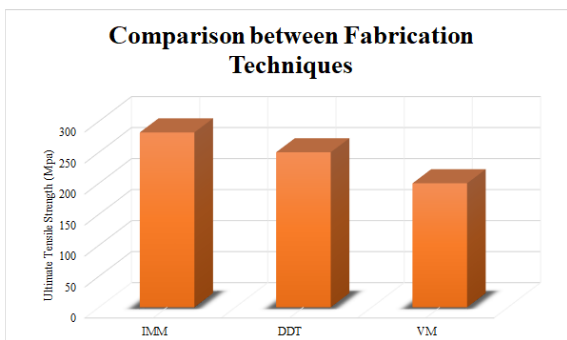

Fig 1. Comparison of Fabrication techniques

Figure 2 depicts the comparison of Yield strength attained with different alloy combinations like Mg-8Zn-1Al-0. Cr-0.5Mg, Mg-5Y, Mg-3Y and Mg-1Y, in order to identify the optimal one.

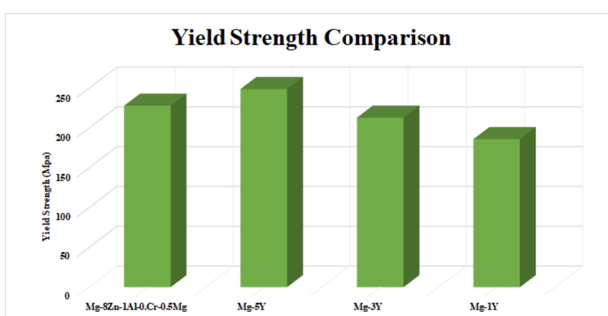

Fig 2. Yield Strength Comparison

From Figure 1, it is identified that the IMM technique possess better UTS of about 282Mpa, compared to other DDT and VN technique that possess an UTS of about 250Mpa and 200 Mpa. Besides, in Figure 2, it is seen that the yield strength of Mg-5Y is high compared to other alloy combinations.

3 Different Processing Approaches and Materials Used For Manufacturing Mg Alloy

In general, materials are considered to be the cornerstones in modern technological developments. The modifications and manipulations in the microstructure and composition of materials results in the formation of advanced materials. Moreover, many different types of processes are involved in manufacturing functionally graded materials and some of the techniques used in recent times for manufacturing Mg composites are explained below.

3.1 Powder Metallurgy process

Powder metallurgy is mainly employed for creating the gradient focused single phase Mg-Zn alloy particles used in this experiment. Due to being cold crushed utilising cylindrical billet, fine Mg particles are first uniformly dry coated with nanometre sized zinc particles. Single phase gradient solid solution is produced with an aid of sintering process, by diffusing zinc atoms into the Mg particles at high temperature. Further, gradual grain refinements are produced in Mg particles, by the gradient concentration of zinc. Moreover, the gradient concentrated alloy particles produced by powder metallurgy technique, gives out improved excellence level with respect to strength, hardness, fracture toughness and ductility, also it is significant compared to unalloyed Mg. The produced alloy exhibits homogenous characteristics in bulk form even with the gradient solid solution composition. Furthermore, the proposed technique also assists in manufacturing near net shape product for higher range industrial applications. However, it is necessary to improve the ductility of the manufactured composite[(16)].

3.2 Selective Laser Melting (SLM)

Aluminium alloys are highly utilized in aircraft industry, because of their increased strength, high ductility, better welding properties and corrosion resistance. An alloy combination namely Al-Zn-Mg-Cu corresponds to improved strength Al alloys and is strengthened with the aid of cold working. Besides, if these alloys possess high Zn contents, solidification process is employed instead of cold working. Moreover, for decreasing the cost, as well as the number of processing steps, a SLM technique is employed. This technique is based on additive manufacturing topology and it employs a layer to layer deposition process, which is regulated by 3D computer model, so as to manufacture completely dense materials that possess intricate and complex geometrics. The SLM technique not only helps in enhancing the component shape, but also gives out increased solidification rate, because of less dimensions in the melting pool. Table 3 lists the chemical compositions of SLM, powder and cast samples.

Table 3. Chemical presentation of cast, SLM, and generated powder samples

Element (wt. %)	Al	Zn	Mg	Cu
SLM	Balance	9.10 ± 0.30	2.33 ± 0.06	1.48 ± 0.02
Cast	Balance	10.90 ± 0.10	2.02 ± 0.01	1.95 ± 0.01
Powder	Balance	11.90 ± 0.03	2.72 ± 0.01	1.41 ± 0.02

In this work, the Al-Zn-Mg-Cu alloy that possess increased zinc contents is synthesized using the defined SLM technique. At the time of processing, because of increased cooling rate, the η particles having reduced volume fraction, compared to cast samples, are produced in the inter-dendritic areas. Further, when exposed to T6 heat treatment, the η particles are invisible and is found to get dissolved in Al-matrix. Once after the T6 treatment, SLM material gives out increased hardness than the cast sample. Nevertheless, the lamellar structure has to be formed, so as to assist with the cooling rate[(17)].

3.3 Comparative Analysis

For investigating the various processing techniques and the combination of alloys used in manufacturing the Mg alloys are discussed in the below Table 4.

Table 4. Comparison of different processing techniques

Sl. No	Author / Year	Methodology	Advantages	Disadvantages	Ref.
1.	Humayun Kabir et al [2020]	This study provides a critical overview of current developments and difficulties in the creation of biodegradable Zn-based materials.	Mg-based biomaterials mechanical characteristics are significantly improved by nano-reinforcements.	The biomechanical characteristics of cutting-edge manufacturing processes need to be studied further.	[18]
2.	Scott C. Sutton et al [2019]	The constitutive behaviour and workability of the proposed alloy is analysed in this study using Gleeble thermo mechanical testing.	Dynamic recrystallization is active at a high rate. It is more accurate at predicting.	To determine whether more strain or annealing produces higher volume fraction of recrystallization, certain investigations are necessary.	[19]
3.	Sampat, Chaitanya et al (2021)	This paper proposed a system for introducing physics-based constraints inside a neural network for a granulation process.	When compared to previous neural networks without physical constraints, the physics constrained neural network (PCNN) IS more accurate at predicting granule growth regimes.	As a result of current physics-based models for granulation, quality assessment may not always be accurate	[20]

4 Different Alloy Proportions Used in Magnesium Based Alloy Manufacturing

Since Mg possess better strengthening effects and appreciable solubility, it is considered to be the vital alloying additions used in Al. In general, the commercial alloys possess Cu contents, either in higher or in lesser amount and this is mainly employed in combination with the Mg alloy, so as to improve the aging characteristics of alloy. Similarly many different alloy compositions are combined with Mg in different proportions, for improving the characteristics of the Mg alloy.

In [21], the difference in tensile properties and microstructural changes occurring in 413.0 alloy, is studied in this work. In this paper, the combination of Mg-Cu-Ag-Ni-Zn-Ce-La-Sr are added to base alloy and the elastic limit, ultimate elongation to structure and tensile strength are measured. Moreover, the influence of Phosphor addition and an impact of heat treatment over the properties and microstructure by base alloy are also studied. Furthermore, the Al alloy casting are represented in numerical values and it highly relies on the mechanical properties. The quality indices of these numerical value are given as,

$$Q = \sigma_{UTS} + d\log\left(E_f\right) \quad (1)$$

In which, the quality of index is represented by Q in MPa, the ultimate tensile strength is given by σ_{UTS}, percentage elongation with respect to fracture is given by E_f and the material constant equivalent to 150 MPa for the Al-7Si-Mg alloy is specified as d. Moreover, the $\sigma_{P(YS)}$ which is probable yield strength for same alloy is expressed as,

$$\sigma_{P(YS)} = a\sigma_{UTS} - b\log\left(E_f\right) + c \quad (2)$$

From the analysis, it is concluded that the combination of Mg-Cu-Ag-Ni-Zn-Sr alloys, leads to increment in YS and UTS values, which is also encountered by a reduction in El percentage corresponding to the base alloy of 412.0 along with a heat treatment. The addition of 0.4% of Mg leads hardening effect and is found to be high or equivalent to that of the addition of 3% Copper. Moreover, that are modified by Sr produces increased tensile properties. Besides, the results achieved shows that alloys which are modified with the aid of Sr in order of 4 to 12% is higher, compared to non-modified 413.0 base alloy in the order of 2%. The addition of Mg or Cu with Sr modified 413.0 alloy leads to a tensile property, which shows that the hardening effect produced by 3% Cu is same as that produced by 0.4% Mg.

In [22] using scanning, transmission and electron backscatter diffraction microscopy, the microstructural development of the steels was investigated, when compared to conventional analysis techniques, EBSD has a distinct advantage in determining the crystal orientation and microstructure. It can perform quantitative analysis and statistical measurement as well as observe different sorts of grain boundaries, their distribution, and their misorientations. According to the findings, grain boundary movement and the onset of the Laves phase were both delayed in steels containing Y. During the grain boundaries at various angles in 0Y, 6Y CLAM steels and lengthy thermal ageing were considerably impacted, whereas those in 71Y and 36Y alloys showed barely any alterations. The chemical make-up of the examined CLAM alloys is shown in Table 5 as percentages.

Table 5. Chemical composition of CLAM alloy (wt. %)

Alloy type	C	Cr	P	N	O	Y
0 Yttrium	0.11	9.3	0.0085	0.0023	0.0060	-
6 Yttrium	0.11	9.4	0.0086	0.0023	0.0054	0.006
36 Yttrium	0.11	9.4	0.0084	0.0022	0.0050	0.036
71 Yttrium	0.11	9.4	0.0084	0.0022	0.0050	0.071

Y concentrations also had a substantial impact on strength and toughness of an aged steels. Y containing CLAM alloys have increasing strength and impact toughness over time due to their stable microstructure. An aged alloys' average previous grain sizes (APGZ; Table 6) are presented in millimetres.

Table 6. APGZ of the aged alloys (μm)

Alloy type	0h	1500h	3000h
0 Yttrium	14.7	15.6	16.9
6 Yttrium	14.3	15.2	16.3
36 Yttrium	11.7	12.9	13.2
71 Yttrium	11.0	12.0	13.1

Table 6 represents the APGZ of the aged alloys the elemental Y increases the carbide stability and microstructural stability. Compared to 0Y steel, mechanical qualities of 36Y and 6Y alloys were superior. However, 71Y alloy's remaining blocky Y-rich inclusions have the potential to reduce the aged alloy's performance. The primary cause of the decrease in USR and the increase in DBTT was the Laves phase precipitation.

4.1 Comparative Analysis

The various material compositions used in manufacturing Mg alloy, along with the techniques employed are discussed in the below specified Table 7.

Table 7. Comparison for different material compositions

Sl. No	Author/ Year	Compositions	Ref.	Advantages	Disadvantages
1.	E. Kavaz et al [2020]	In this paper, a (25ZnO.75TeO2)100-x.(Ta2O5)x (x = 0, 1, 2,3 mole) Composition and Zinc Tellurite glasses are doped.	[23]	As Ta2O5 contribution increases, the glass samples radiation attenuation properties improves.	Due to a common extinction rates of pure tellurium oxide, additional constituents are required to produce the glassware.
2.	Andrzej Pawlak et al [2019]	TLS Technik GmbH and Co Spezialpulver KG's AZ31 alloy powder with a fraction of 45 to 100 mm is the compositions are presented in this study.	[24]	The current mechanical characteristics are improved.	Due to its high affinity for oxygen and the resulting processing restrictions, Mg is not commonly used.
3.	Arash Fattah-alhosseini et al [2020]	This work presents the compositions comprising of Mg and its alloy that are used in the plasma electrolytic oxidation process.	[25]	Through improved microstructure, harmful penetration from the coating to the substrate is decreased.	The presence of surface porosities and deep pores and affects a coating's ability to resist corrosion.

Moreover, an analogization is carried out amid the different material compositions used in manufacturing Mg alloy, with respect to mechanical parameters namely yield strength and tensile strength.

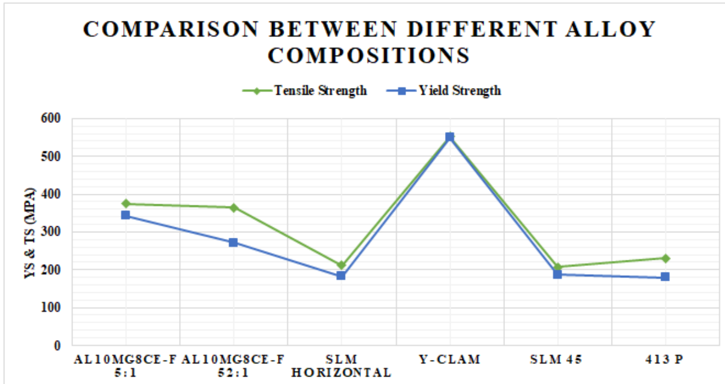

Fig 3. Comparison for different material compositions with respect to Mechanical parameters

From the analyzation amid different alloy proportions, with respect to the mechanical parameters, it is concluded that the Y-CLAM, possess better tensile strength and yield strength of 550Mpa than other conventional compositions as specified in Figure 3.

5 Overall Discussion

The defined review paper mainly deals with the impacts of Yttrium alloy over the Mg based alloys. Here, the different fabrications techniques and the alloy proportions employed in the development of Mg-based alloys are investigated. Initially, a comparison is carried out amid the fabrication techniques like IMM, DDT and VM, with respect to UTS. Further, an analogization is performed between the different alloy combinations like Mg-8Zn-1Al-0.Cr-0.5Mg, Mg-5Y, Mg-3Y and Mg-1Y in terms of YS. Further, a comparative analysis is carried out between the different alloy proportions namely Al10Mg8Ce-F 5:1, Al10Mg8Ce-F 52:1, SLM Horizontal, Y-CLAM, SLM 45 and 413 P. The analyzation results depicts the significance of adding Yttrium alloy with Mg based alloys and also shows the effectiveness of it on the mechanical and microstructure of Mg-Zn alloys.

6 Conclusion

This study focuses on techniques and material combinations used in manufacturing Mg based alloys to improve the mechanical properties and to increase the tensile strength. China low activation martensitic (CLAM) steels with different yttrium (Y) contents are utilized. A fabrication of reinforced composites namely Al-Zn or Fly Ash or SiC is carried out by Stir Casting Route using Vortex Method. Powder metallurgy route is employed for preparing Al-Zr relied metal matrix composites. Further, a comparative analysis is carried out between the different alloy proportions namely Al10Mg8Ce-F 5:1, Al10Mg8Ce-F 52:1, SLM Horizontal, Y-CLAM, SLM 45 and 413 P. Y-CLAM achieves high tensile and yield strength of 550Mpa when compared to the other techniques and enhances the eutectic temperature corresponding to Mg-Y-Zn alloys, which further improves the dynamic recrystallization temperature. In the future, the CLAM steels has to be improved for the upper application temperature and irradiation resistance.

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