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Wear Behaviour of Magnesium Metal Matrix Hybrid Composites –A Detailed Review

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Abstract

Magnesium Metal Matrix Hybrid Composites (MMMHC) are promising and potential materials for several applicationlikeadvancedengineeringapplications,transportationsector,defence,andaerospaceorganizationsduetophysicalproperties,density, high buckling resistance, good castability, and high specific strength. Moreover, several approaches like dry sliding, friction are proposed in past to improve the stiffness, specific strength, damping behavior, mechanical properties, and minimize the reduction cost of magnesium hybrid composites. By the validation, performances of MMMHC are mostly depending upon the combination of reinforcing material. This paper has discussed the review of various combinations of the reinforcing materials, which are used for magnesium metal matrix, the effect of reinforcing materials in magnesium and alloy, merits and demerits of magnesium metal matrix. Also, the effect of reinforcement is in mechanical properties like hardness, tensile strength, strain, and ductility are discussed. Moreover, future researches for improving MMMHC are suggested in this work.

Keywords: Tribology; Wear behavior; Magnesium metal matrix; Composites.

Introduction

In recent years, many of the industries such as automobile, mechanical, and aerospace are identify the Metal Matrix Composites (MMC) of increased information [4]. Due to the low density, composites and magnesium alloys are attracted to major research purposes. The major role of hardness is selecting the MMC for different industries like automobile. Moreover, MMC is a merged material and it has two-ingredient elements like ceramic and organic compounds [5]. Thus the various part of the MMC is composited with various hybrid metal matrix because of their potential application such as automobile industries, aerospace, and space equipment [3]. Furthermore, Magnesium Metal Matrix Composites (MMMC) have certain good properties like hardness, evaluated temperature, room tensile strength, weight saving of unreinforced alloys, and elastic module [6]. The utility of reinforcement in composite material has the role of enhancing the mechanical property of resin system. Particulates or different fibers are used for composites the changing properties of composite in good way [32]. Also, the matrix is generally used for lighter materials like titanium, aluminum, and magnesium and it provides support of reinforcement during structural applications [50]. Thus Magnesium atomic number is 12 and it is low weight, pliable metal, soft, high yielding, long-lasting, and looks like the color of white-grey [7]. Moreover, MMMHC has a thickness of 2-3rd of aluminum and machined by easy casting, extruded and drawing. Moreover, magnesium is high caustic for the attendance of magnesium oxide thin layer also it has prevented the oxidation [8]. Although reinforced material of MMC is arranged for some techniques consists of stir casting, mechanical alloying, squeeze casting, powder metallurgy, and infiltration [9]. Thus the alloy and magnesium are gain common attention for the research of scientific and energy conservation of commercial application. For the low density, the performance of the demand becomes increased [10]. These Magnesium Metal Matrix Hybrid Composites (MMMHC) properties are most useful for reducing greenhouse emissions and reduce fuel consumption. Hence the reinforcement is wanted to improve the base metal properties and the fabricated MMMHC has provided more attraction to aluminum MMC [7]. However, the structure of lightest metal and MMC display lot of advantages under magnesium alloys or monolithic magnesium [11].

The advantages of Magnesium alloy it has talented structure, machinability is good, have greater dimensional stability, recycling potential is high and its thermal conductivity is also high [12]. Even though magnesium alloy has these advantages it is used very limited applications as it has very poor wear resistance, low strength, creep resistance is poor in high temperature [13]. Now a day's usage of MMC has been increased in industries as it has good Tribological and mechanical properties. MMC is designed by including different hard ceramic particles which Include SiC, B_4C, Si_3N_4 etc. along with lubricating materials which include BN, TiO_2, graphite, etc,[16].Along with this, Reinforcement over base metal is considered as the improved method. MMC which is got from magnesium is considered as a better choice for Al MMCs [14]. The important thing in this is the reinforcement must be unchanged and non-reactive at the working temperature. The reinforcement increases the hardness; wear resistance, tensile strength of both Magnesium and its alloys. In mechanical properties distributing particles plays a vital role in MgMMC. While reinforcing TiC it shows an improved yield strength, tensile strength, and reduced ductility to certain level [16].In the same way, while reinforcing Al_2O_3 it has better compressive strength and encourages creep resistance [15]. Creep strengthening takes place in fibber and matrix during load transfer between plastic flows. Next is the reinforcement of CNT in Magnesium Matrix composites [36]. This results in improved bonding strength, wettability, tensile strength of magnesium and sometimes it may also weaken the base plane of the surface [17]. The next element considered for reinforcing process is Boron Carbide [33]. It is a well-known hardest element with high elastic modules and load-bearing. When boron carbide is added to magnesium it gives an increased bonding strength, hardness, wear resistance [18]. Manufacturing techniques carried out in MMC are based on the nature of the material and fabrication equipment. Some of the technique is Stir Casting, Chemical Vapor Deposition, In-Situ Fabrication Technique, Squeeze Casting, Powder Metallurgy and Physical Vapor Deposition [48]. These manufacturing techniques have a major part in defining composite's physical appearance and in developing various mechanical properties. Now day's nano particles are also used in reinforcement as it has improved properties in depositing minimal weight percentage without disturbing the bulk properties.

Magnesium Metal Matrix Hybrid Composite

MMMHC is used in different applications for both the commercial and scientific fields [21]. Hence, the commercial field has included energy conversion and in scientific research like Space, defense [20], Aerospace, Automotive, vehicle Industries because of their good physical, mechanical properties and low density along with less fuel consumption save the environment [23]. In general, the Mg alloy is not used in various applications due to low wear temperature, low strength and high temperature in poor creep resistance [24]. To influence its strength, damping behavior, creep properties, stiffness, wear behavior the metal matrix is added with reinforcing materials [25]. The metal matrix composite which is fabricated from magnesium alloy is good alternative compared to the metal matrix composite made of Aluminum [26]. The reinforcement which is generally used in magnesium alloy is of ceramic type. Some commonly used ceramic reinforcements are shown in fig. 1.

Harprabhjot Sing *et al* [9] worked in bringing up a Hybrid Metal Matrix Composite with Magnesium as base by using in situ effects. During in-situ production, the bonding in the matrix is good where the Micro and Nano combine with Magnesium melt [23]. Here the Magnesium melt is combined with Ceric Ammonium Nitrate to generate Cerium Oxide and Magnesium Oxide at a certain temperature of 670 ^{0}C and 870^0 C. to find the nature of the particle it is investigated under Energy Dispersion Spectroscopy and in X-Ray Diffraction. The size and its Morphology are jotted with Scanning Electron Microscope [27]. The Mechanical outcome of the designed MMC is verified by its Hardness, Scratch Test and Compression. Its deformation behavior is examined with 3D OpticalProfilometer.TheendresultshowsvarioussizesandtypesofCeO_2, MgO, and CeMg12 in the in-sit structure.

Magnesium alloy is the base metal matrix and it is combined with Silicon and Alumina. Karthick *et al* [1] proposed a supporting ceramic material that shows changes in its characters while used in various applications [44]. This Hybrid MMC has undergone various mechanical studies in different fields like Microstructure, X-ray diffraction, Scanning Electron Microscopy (SEM). The defining hardness observation results show variation in its hardness [45] and the value varied to 75.16 from 64.52HV. From this, it's clear that the Metal Matrix Composite hardness is manipulated when the Silicon Carbide and Alumina are added to the Magnesium Alloy [41].

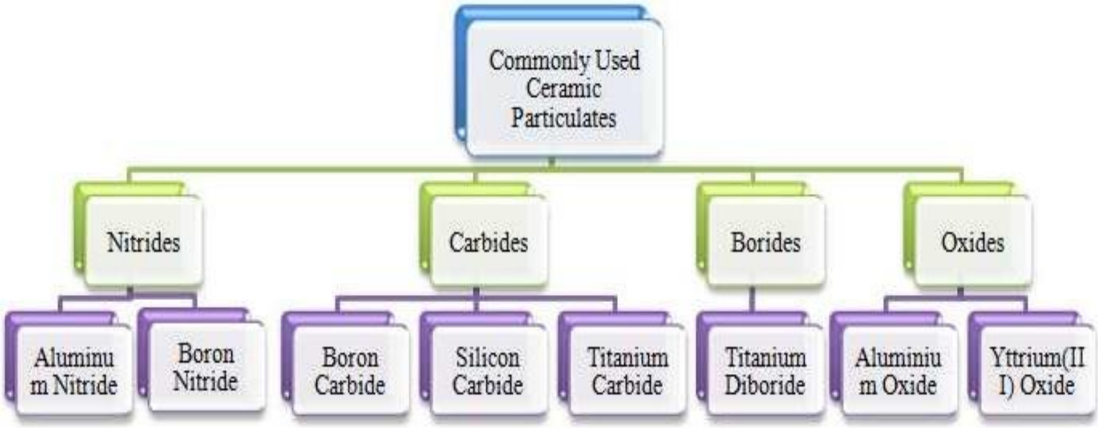

Fig.1.Commonly Used Ceramic Reinforcement.

Density Measurement

Magnesium density measurement of MMC is shown in Table 1 [1], which describes about the changes that take place in magnesium density when it is reinforced through Alumina and Silicon Carbide. When the content of Silicon Carbide in combination increases the density of the Composite is also increased [46]. It is examined that when the density of Silicon Carbide is varied from 0 to8%thenthe density value israisedtoabout14.66%.

Table1. Magnesium Density Measurement from 95-87%.

Model	Percentage of Magnesium Alloy AZ31	Density[1]
1	95	1.72
2	94	1.798
3	93	1.80
4	92	1.89
5	91	1.90
6	90	1.92
7	89	1.93
8	88	1.95
9	87	1.96

Hardness Properties

When the percentage of Silicon Carbide increases in Hybrid MMC the hardness of the material is also increased. There as on behind this is the silicon particle which is located in flow lines and behaves as obstacle by interrupting the movement in the matrix [49]. When the reinforcement of Silicon Carbide is changed between 0-8 wt % then there is an increase in hardness of Magnesium upto16.4%. Hence it clear that SiC provides high-performance Magnesium composite in low cost. Moreover, the measurement of hardness is shown Table2 [1] discuss about the result of early research A356/Silicon Carbide and Al-Si/Silicon Carbide which reinforced to form Aluminum Oxideand Silicon Carbide along with the precipitates obtained from SEM because of its greater strength and hardness [47].In addition to this, the reduction of size of its grain is also areas on for increasing hardness.

Table2.Measurement of hardness

MagnesiumAlloy	Hardness(hv)	Load(gm[1])
95	64.4	200
94	67.3	200
93	69.6	200
92	69.3	200
91	67.8	200
90	72.1	200
89	73.1	200
88	74.7	200
87	75.2	200

[1]gram

Wear Behavior in Magnesium Metal Matrix Hybrid Composite

Magnesium alloy is used to analyze Matrix's Microstructure, reinforcement distribution, wear track of SEM, and optical microscope [31]. The result describes that Hybrid composite has a good wear resistance property comparatively. When the load applied increases shows an increased wear rate. Furthermore, wear analysis of some hybrid composites are describedinTable3.

Table3. Wear analysis of few hybrid composites.

Combination used	Condition	Wear test Method	Load	Sliding Speed	Distance	Observation
AZ31B With Nano-Composite	Sliding Wear Behavior	Pin-up-disc wear test	10N	0.060 to 1.2m/s[1]	2000m	The result shows lower Wear rate when compared withAZ31B
AE42 with Saffil short Fibers and SiC Particle	Sliding Dry Wear	Pin-on-disc wear test	10N-40N	0.837m/s	2.5km	The result has better wear Resistance compared to Unreinforced Magnesium
SiC particle On Mg Hybrid Particle	Dry Sliding Wear	Ball-on-Disk	30N	0.1m/sand 0.2m/s	200 m	Wear decreased while Increasing sliding speed

[1]Meter per second

A atthisugan*et al* [5] show the test study of materials like AZ91D supported B_4C and Gr forms a hybrid composite which is produced under Stir Casting Process. From the result obtained the tribological and mechanical properties show a lower wear loss of magnesium. Also reinforced Graphite reinforcement is compared to unreinforced alloy [38]. When the content of Boron Carbide is increased monotonically the wear resistance also increases with the hardness. After this process is carried out final tensile strength gets decreases. In addition, this study clearly explains about the wear resistance of Magnesium Alloy increases when added with both Soft Reinforcement like Graphite and Hard Reinforcement like Boron Carbide. Hence the result concludes that Hybrid Magnesium has a major role in the Automotive and Aerospace Engineering Sector as it has ultimate tensile strength, greater strength, and its wear-resistance composites [40].

Kavimani*et al* [31] are studied AZ31 reinforced by changing SiC weight percentage of doped Reduced Graphite Oxide (R-GO). To know more about its Tribological actions of this particular Metal Matrix Composites the control factors like sliding distance, sliding velocity, and applied load are varied [42]. From the result, it is concluded that increasing the reinforcement shows better wear resistance. The Metal Matrix Composite which is made of 20 weight percentage of Silicon carbide doped reduced graphite oxide (r-GO) has reduced wear rate and this is the best doping percentage of nano sheets (r-GO). If the value increases it results of wear resistance will decrease [37]. After the incident of decorticate and scrape evident clearly about the wear mechanism of the designed MMC. Some of the existing techniques of wear behavior MMMHC authors. Combination merits and demerits are mentioned in Table 4**.** The process carried out in examining the Tribological behavior is semi-powder metallurgy.

The result shows an improvement in hardness while adding doped reinforcement and also minimizes wear loss. The Tribological property is improved when SiC doped r-GO is added to Magnesium Alloy.

Table4.Merits and demerits of few compositions.

AUTHORS	MAGNIESUM ALLOYCOMBINATION	MERITS	DE-MERITS[1]
Kavimani*etal*[31]	AZ31 Mg alloy including SiC doped with r-GO	Improves wear resistance of MMC.	If amount of SiC to r-GO crosses the limit it exhibits greater wear rate
Aatthisugan*etal* [5]	Magnesium (AZ91D) with Graphite and Tungsten Carbide	Magnesium Hybrid composite results with greater strength, wear resistance, and Hardness. WC in this process helps in increasing the ability to carry more load and the graphite particles behave as solid lubricant which lowers the wear rate.	When WC is increased it leads to micro-cracks over the surface
Mondal*etal* [22]	Magnesium Alloy (AE42), with Saffil short fibers and Silicon Carbide particles	This hybrid composite shows good wear resistance with longitudinal direction and high load-bearing capacity.	Wear rate of transverse is higher as it has worn surface and load-bearing capacity is lower.
Jo *etal*[33]	Result of particle size SiC on Magnesium based Hybrid MMC	When the particle size of the SiC is greater, it shows an improved wear resistance. This shows that is it applicable for several tribological like brake, rotors, and cylinder liners for automobiles.	Small-sized particles of SiC are not applicable for several tribological applications.
QumrulAhsan*etal*[34]	Silicon Carbide and Multi-walled Carbon Nanotubes in Magnesium Hybrid composites	The friction coefficient value is higher than pure magnesium alloy. Wear Resistance is high in Composite. Wear rate is less in hybrid composite compared to pure Mg	
NavinNiraj*etal*[35]	Reinforcing Magnesium MMC with Fly Ash Cenospehere	Fly ash hardness of addition composite was increased. The vital tensile strength is increased by Adding fly ash Cenospehere.	While the fly ash content increases sometimes compressive strength will decrease.
Thirugnanasambandham *etal*[39]	Al_2O_3reinforced Mg based MMC	When the deposition of Alumina nano particle over magnesium the wear rate decreases and improves the friction co-efficient.	When deposition increases wear rate increases

Adhesive-Abrasive Wear

Abrasive Wear occurs when the thick element is dragged and strained on the solid surface. The thick element includes aluminum oxide, silicon carbide, and so on. The three body abrasive or the Rolling Abrasive generally occurs when the particle is rolled. Adhesive wear takes place in between the two solid surfaces while contact each other. Here during contact, it either transfers the material or loss the material. This is not a frequent process like abrasive. It takes place when the material slides each other without any lubricant. Alahelisten *et al* [43] examine the wear mechanism using X-ray Spectroscopy, SEM, and Light Optical Microscopy (LOM). Abrasion wear rate defines the quantity loss of material for all sliding distances. In this, the magnesium shows a linear improvement in two-body abrasion resistance when the fiber content is increased.

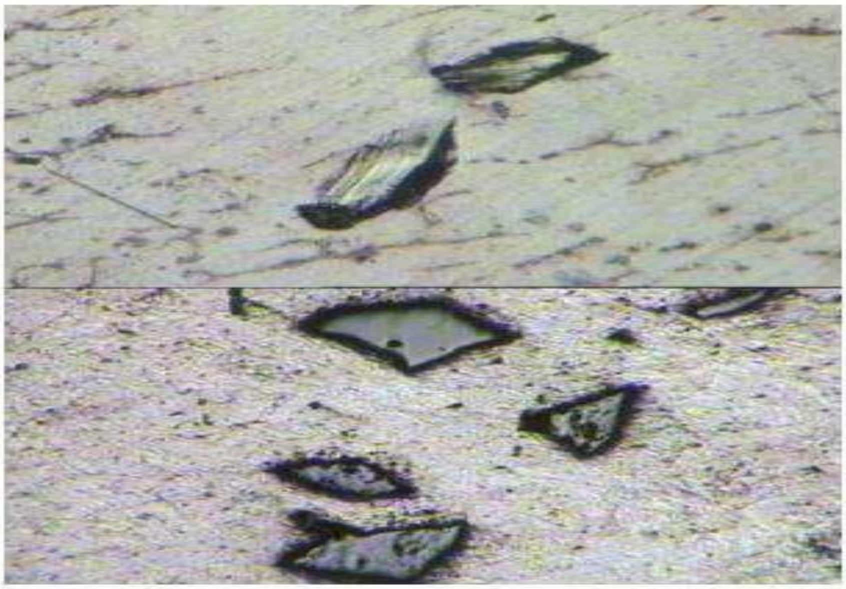

Fig.2.Aluminium metal composites between B_4C and SiC[36].

R.Ipek [44] proposed characteristics of adhesive wear of B_4C and *SiC* between 10to20wt and the Metal Matrix Composited (MMC) has 20% of weight. *SiC* Contained percentage is produced liquid metallurgy under wet sliding conditions. The microstructure AMC of reinforced B_4C 20wt and *SiC* 20wt are exposed in fig.2. Furthermore, the obtained outcome of wear resistance may increase by B_4C alloy. Thus the overall relationship of wear mechanism and wear resistance are observed in this technique. The model attains light adhesive in some conditions of wear trace.

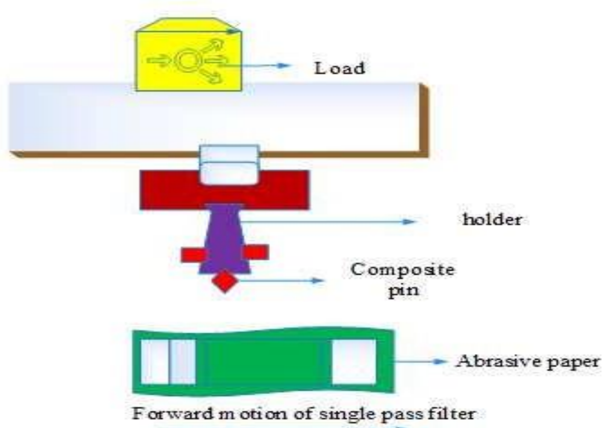

Fig.3.Linear abrasive wear.

Tribo material had low friction of coefficients and contained resistance are in different modes like erosive, fretting, adhesive, reciprocating, abrasive, and so on. The majority of the time, the fiber indicates better development in adhesive wear mode but, complicated to improve significance and base matrix performance. So Sanjeev Sharma *etal* [45] introduced High Molecular Weight Polyethylene (HMWPE)to enhance the performance of micro counters.
Moreover, micro-series contains 6 filled composites packed by *SiC* and nano series contains 8 composites packed by *SiC*. For *SiC* increase, the hardness of overall series also increased. In this paper, physical and mechanical properties are observed depends upon *SiC*. The outline of linear abrasive wear is shown in fig. 3. This technique observed single-pass linear motion, wear resistance, and amount of optimum micro filler. But this model accomplishes low hardness with SEM and also the micro-cutting mechanism of abrasive wear is low in the nano composites.

Melt Wear

Rajiv Chaudhary *et al* [46] studies the tribological and fabrication testing of composite fly ash aluminum. The selected MMC are reinforced with fabric and aluminum fly ash, the metal matrix percentages are fabricated with metal composites. Moreover, the author introduced a stir casting technique to produce the weight of fly ash aluminum by the use of MMC. Tribo pairs are formed among the soft surface of iron disc and soft MMC pin. The result of this model attains 6% wt in aluminum fly ash and fly ash content as 4% wt. Furthermore, it gives the small rate of coefficient friction involving cast iron tribo pairs and MMC [49]. The variation of wear gm is mentioned in Table 5.

Table5. Variation of wear behavior.

Wear (gm)	Sample[1]
0.45	
0.44	Low fly ash
0.43	
0.42	
0.41	
0.40	Medium fly ash
0.39	
0.38	
	High fly ash
0.38	

Major issues of rail electromagnetic launches are transition and it restricts the routine of electromagnetic. During launch improvement, contact surface contained wear can affect the structure of morphology and armature. So Lixue Chen *et al* [47] have proposed contact of wear resistance, sliding friction, armature to understand the importance of rail and suppress transitions. Moreover, the author designs an armature to make a wear contact of armature surface. That designed armature is used for rail launch research and used for calculating wear rate of melt wear also affects obtained in load is observed. The result of there plica is to absorb the heat produced surface of melt wear. Furthermore, the outcome of armature contact resistance through 80mm^2areas is 2.56□□□and 50mm^2area is4.09 □□□also coefficient of sliding friction is +0.11.

1. Performance Metrics

The overall performance of MMMHC is elaborated in this section. The specific density of the MMMHC performance is compared to the existing techniques. Some performances of metrics are mentioned in Table 6.
The author describes about the performance analysis of Magnesium (AZ91D) reinforced with Graphite and Tungsten Carbide. The wear rate is decreased when tungsten carbide is added to Magnesium. Other properties of this combination are explained in fig. 4.

Table6.Metrics assessment.

Authors	Usedcomposites[1]	hardness	density	wear	Tensile strength	Load
Karthick.E *etal*[1]	AZ31,Al_2O_3,SiC	75.16	1.9681			200
JeyaBharathyandMathiazhagan[2]	AZ01andTiO_2	65.8	1.81	2.8	84.3	40

Aatthisugan*etal* [5]	AZ91D,B_4C and Gr	20.5	1.8091	2.5	62.1	55
HimaGireesh*etal*[6]	Al6061	30	2.67	3.14	115	20
RaviButola*etal* [7]	Al metal composites	60	2.58	10	68.24	30
KumarandMondal [11]	AE42magnesiumalloy	70	3.3	2.25	200	20
Arokiasamy and AnandRonald[14]	FCP	64.7	1.738	6.05	135	15
Xuezhi*etal* [15]	AM60,and Al_2O_3	75.23	3.3		40	
DavidRajaselvam*etal* [19]	Al6061,Fly Ash, SiC_p	40		5.25	173	15
Karla*etal* [27]	SiC, Al_2O_3 and MMC	87	2.69		259	
Venkat*etal* [29]	AlSi10Mg, Fly Ash and graphite HMC	89	2.64	9.47		81

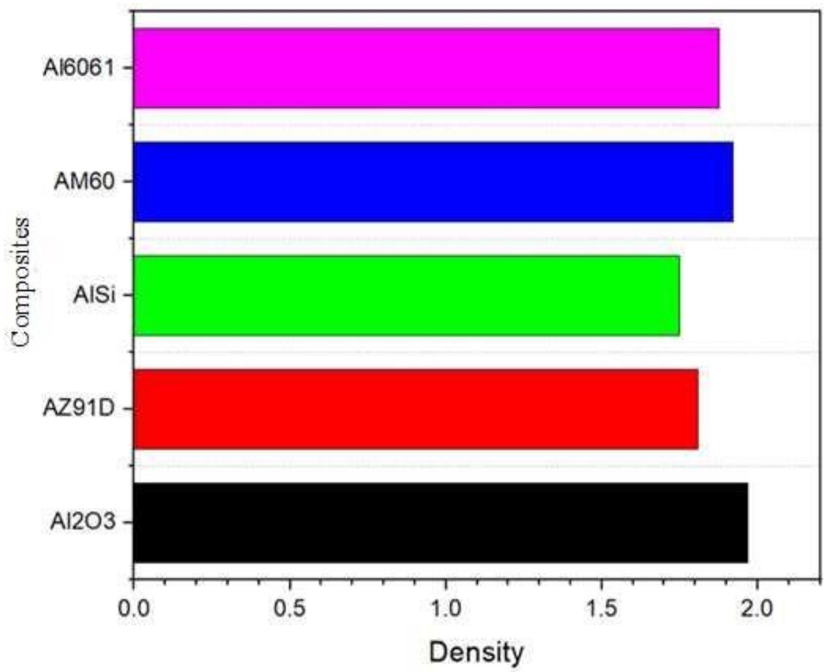

Fig.4.Comparison of density.

The parameter values to estimate the composites wear behavior was shown in fig.5. The key parameters of magnesium composites were described in fig. 5. Magnesium alloy has greater bulking resistance, good castability, greater specific strength with low density is considered as the upcoming material for transportation division [28].Here the material is fabricated using magnesium supported titanium Dioxide along with graphene which forms a hybrid metal matrix composite that is made up under Stir Casting Technique [29]. Here a test called Dry Sliding is carried out pin disc tribometer in order to examine the loss of wear volume [30]. At this time steel disc is taken as counter face and a test is carried out in normal load which ranges from 20-80N. From the result obtained lesser wear volume loss when compared to unreinforced Magnesium Alloy.

Fig.5.Performance Metrics of Magnesium (AZ91D)/Graphite/TungstenCarbide.

The overall performance assessment of few methods was elaborated in fig. 6, the composites used for validation are shown in fig. 6.

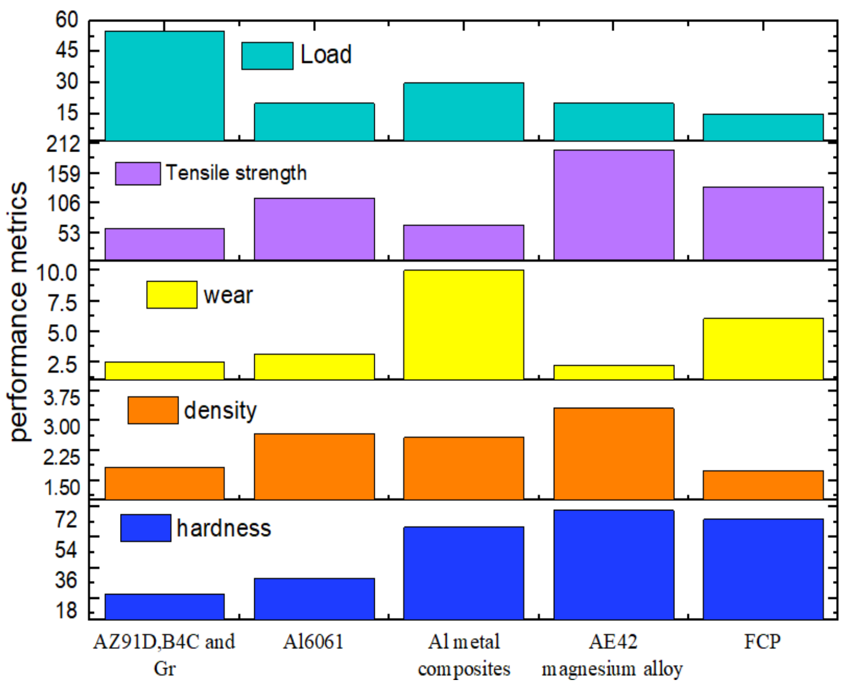

Fig.6.performance metrics assessment.

Discussion

Several existing replicas were discussed to improve stiffness, mechanical properties, specific strength, chemical properties, etc. Some techniques to reduce the cost of MMMC are discussed. Furthermore, observed the overall performance metrics of density, hardness, load, wear, and soon. The wear behavior of MMMHC and their measurement of hardness, density are discussed in this paper also observed the ceramic reinforcement properties which are commonly used for the metal composites. In addition, the wear behavior of the MMMHC is discussed, and gained performance metrics like sliding speed, wear test, and load of existing technique is compared and studied. Additionally, wear behavior advantages and disadvantages are described in this paper. Hence, the short summary about review is showninfig.7.

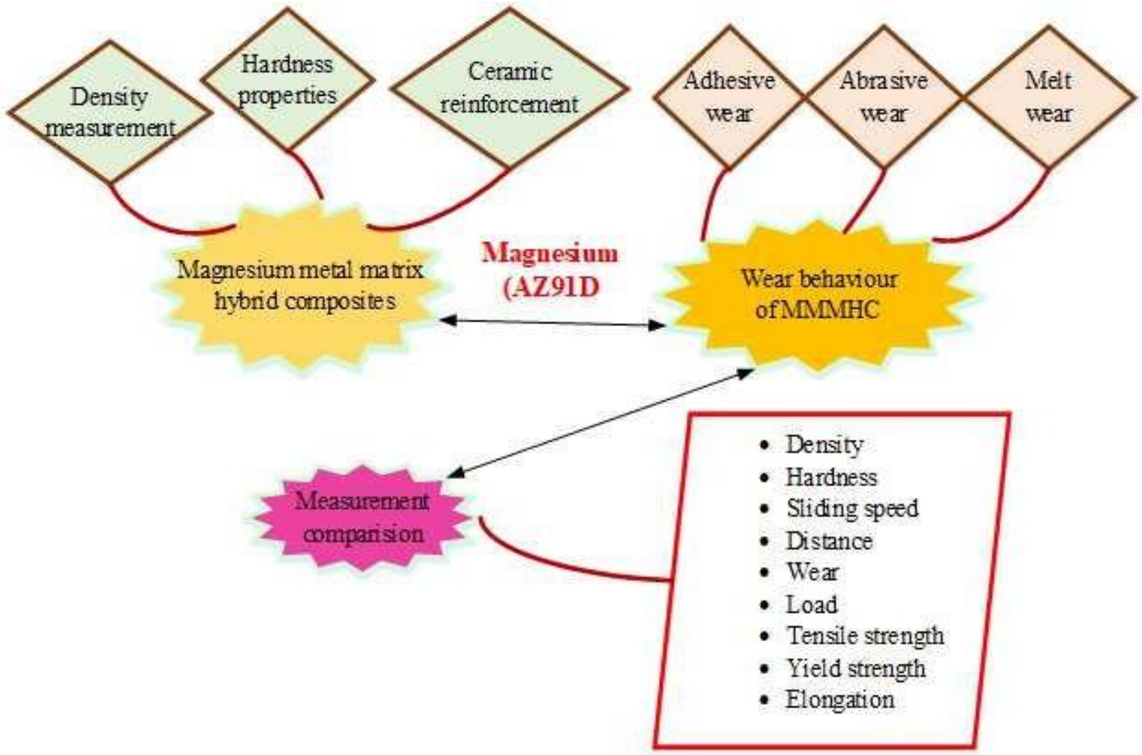

Fig.7.Short summary about review.

Several studies were discussed related to magnesium metal matrix composites. Hence, each literature has shown different tribological behavior, which means variation in wear and shear rate. Some hybrid composites have obtained high wear rate, this may tend to reduce system performance. So in future, designing an efficient optimization procedure will provide better optimized wear rate.

Conclusion

In order to harden the magnesium matrix composite to use in different applications like engineering, automobiles, and space, aerospace various processes are carried out. This conclusion crisply explains about the wear resistance, hardness, and creep resistance when reinforced with different alloys. The Magnesium MMC which is reinforced by SiC results in high creep and wear resistance when compared to Magnesium MMC is reinforced by Al2O3. AL2O3independently reinforced Mg MMC has high rate of wear resistance when comparing CNT reinforced Mg MMC. While Mg MMC reinforced by CNT, it results in better wetability and strength of bonding composites. Moreover, Magnesium wear resistance MMC is high when comparing base alloy. In addition, the highest wear resistance is obtained when it is combined with AZ91-6.5-UST.When reinforcing MGMMC with Boron results in better bonding strength of the composite and it also results in better flexural strength. Tensile strength is improved by adding fibers in the magnesium alloy which also reduces the ductility of the composite. In future, designing an optimization framework to estimate the composites behaviors will tend to attain the best results.

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