A Review on Nanocarbon Materials for Magnesium and Aluminum Metal Matrix Nano-Composites

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Abstract

Rapid innovation in nanotechnology in recent years enabled development of advanced metal matrix nanocomposites (MMNCs) for various demanding fields of engineering and medicines like aerospace, defense, automobiles, electronics, materials, chemistry, energy, environment, information & communication, consumer goods biotechnology etc. Carbonous material such as graphite, carbon nanotubes (CNTs), carbon foams, carbon nanofibers (CNFs) and graphene are attractive reinforcement materials for self-lubricating MMNCs due to excellent electrical, mechanical and thermal properties along with lubricious nature. These materials act as solid lubricants in aluminum, titanium and magnesium MMCs for lightweight applications where liquid lubrication is difficult or ineffective. Moreover, liquid lubricants are not environmental friendly, releases some quantities of pollutants into the environment. The development of self-lubricating MMNCs is very important for green or environmental friendly tribology. However, there is still some challenging problems that need to be resolved such as agglomeration of nano-size particle, low wettability and a poor interface between particles and matrix. The results reveal that reinforcing self-lubricating carbonous materials to metal matrix decrease both coefficient of friction and wear rate.

Keywords: metal matrix nano-composites, Nano-carbonous materials, Light weight composites

1. Introduction

In recent era the light weight materials such as aluminum and magnesium in demand due to energy crisis and environmental issues. Aluminum (density 2.77g/cm^3) due to its good corrosion and oxidation resistance, high ductility and high strength, high electrical and thermal conductivity with relatively low cost find tremendous application in packing, electrical applications and aerospace and transportation industries [1-4]. Moreover magnesium (density 1.74g/cm^3) is competing with aluminum due to its high specific strength and modulus. magnesium alloys have good damping capacity and castability [5]. The component of aerospace and automobile industries fabricated with aluminum and magnesium alloys have to work in high temperature and harsh wear environment, where lubrication by liquid lubricants is difficult or impossible. Also lubrication by liquid lubricant pollute the environment by releasing harmful by product or gases. In such circumstances lubrication by solid lubricant can be very effectively done. Carbonous material such as graphite, carbon nanotubes (CNTs), carbon foams, carbon nanofibers (CNFs) and graphene are attractive reinforcement materials for self-lubricating MMHCs due to excellent electrical, mechanical and thermal properties along with lubricious nature [6]. Superior properties of MMHCs reinforced by carbon nanomaterials is due to metallurgical factors, such as HallePetch effect by grain size refinement, Orowan looping and dislocation generation resulting from thermal mismatch between the matrix and reinforcements [7] . In this article the main objectives are following:

- The review mainly focuses on a wide array of research conducted in the field of carbon nano materials reinforced aluminum and magnesium MMHCs.
- Nano carbonous material embedded for self-lubrication and their effect on mechanical and tribological properties of aluminum and magnesium based MMHCs.

2. Nano carbonous materials

Carbonous nanomaterials such as SWCNT,MWCNT, Graphene, CNFs and graphite nano paltelets exhibit a wide range of unique properties, including large aspect ratio, exceptional high Young's modulus and strength, excellent electrical and thermal conductivity [8, 9]as shown in table 1.

The fabrication of carbonous material reinforced MMHCs can be fabricated using four different processessing such as Liquid metallurgy route, thermal spray processing, powder metallurgy and electrochemical deposition. Liquid metallurgy route includes melt stirring, melt infiltration and laser deposition, thermal spray processing includes plasma spraying, high velocity oxyfuel spraying, flame spraying and electric arc spraying, powder metallurgy route includes powder mixing, stirring and hot pressing and spark plasma sintering and electrochemical deposition includes electroplating and electroless plating [10-16] as shown in figure2.

Table 1: Properties of different Carbonous materials [8]

Nano Carbonous Materials	Diameter, nm	Tensile strength, GPa	Tensile modulus, GPa	Thermal conductivity, W/mK
CFs	7000	3.65	231	8.5
SWNT	1-2	-	1000	3500
MWNT	5-50	150	270-950	500-2069
CNF(graphitized)	50-500	235	245	1950
Graphene	-	130	1002	4840-5300

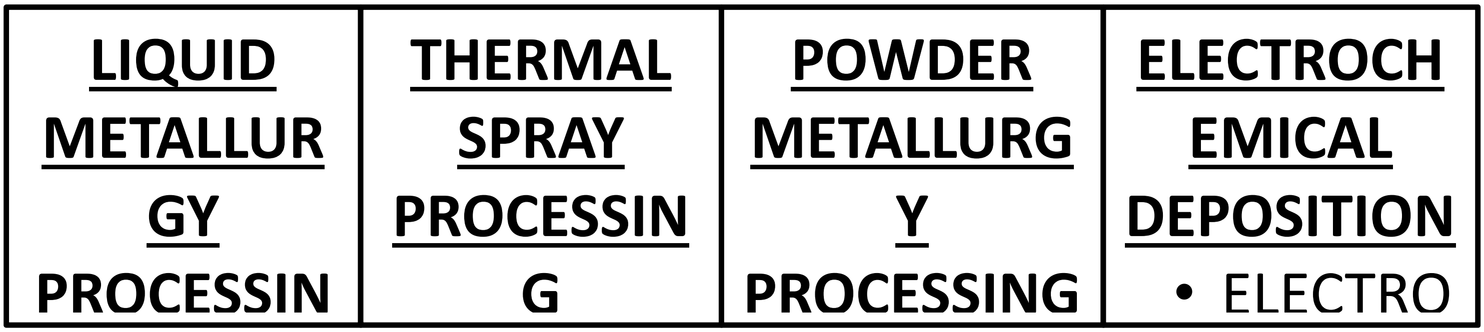

Figure. 2: fabrication techniques

3. Carbonous reinforced Aluminum & Magnesium MMCs

Limb et al. [17] fabricated A7xxx-CNF nano-composite using liquid metallurgy route and analysis the effect of CNF on Al7xxx aluminum alloy. It was found that Due to CNF reinforcement strength of alloy was increased by 38%. It was also reported that addition of 0.76wt% CNF in Al7xxx alloy increase the tensile strength by 33%, Ultimate tensile strength by 55% and elastic modulus by 17% than that of base alloy matrix. .Aatthisugan et al.[5] experimentally studied the micro structural and mechanical behavior of unreinforced AZ91D magnesium alloy, AZ91D-B_4C composites andAZ91D-B_4C-Gr hybrid composites fabricated by stir casting. They have reported an increase in density with addition of B_4C in AZ91D and further it slightly increased with embedment of graphite as AZ91D-B_4C-Gr hybrid composite. The porosity showed lower value for AZ91D-B_4C composite and further lowest value for AZ91D-B_4C-Gr hybrid composite. This decrease in porosity was due to uniform stirring speed and also size of reinforcements. The results also revealed that AZ91D-B_4C composite and AZ91D-B_4C-Gr hybrid composite had superior hardness and ultimate tensile strength (UTS) than base AZ91D magnesium alloy. Metallographic analysis shows uniformly distribution of B_4C and graphite particles throughout the AZ91D matrix phase with lack of cracks as shown in fig. 4.

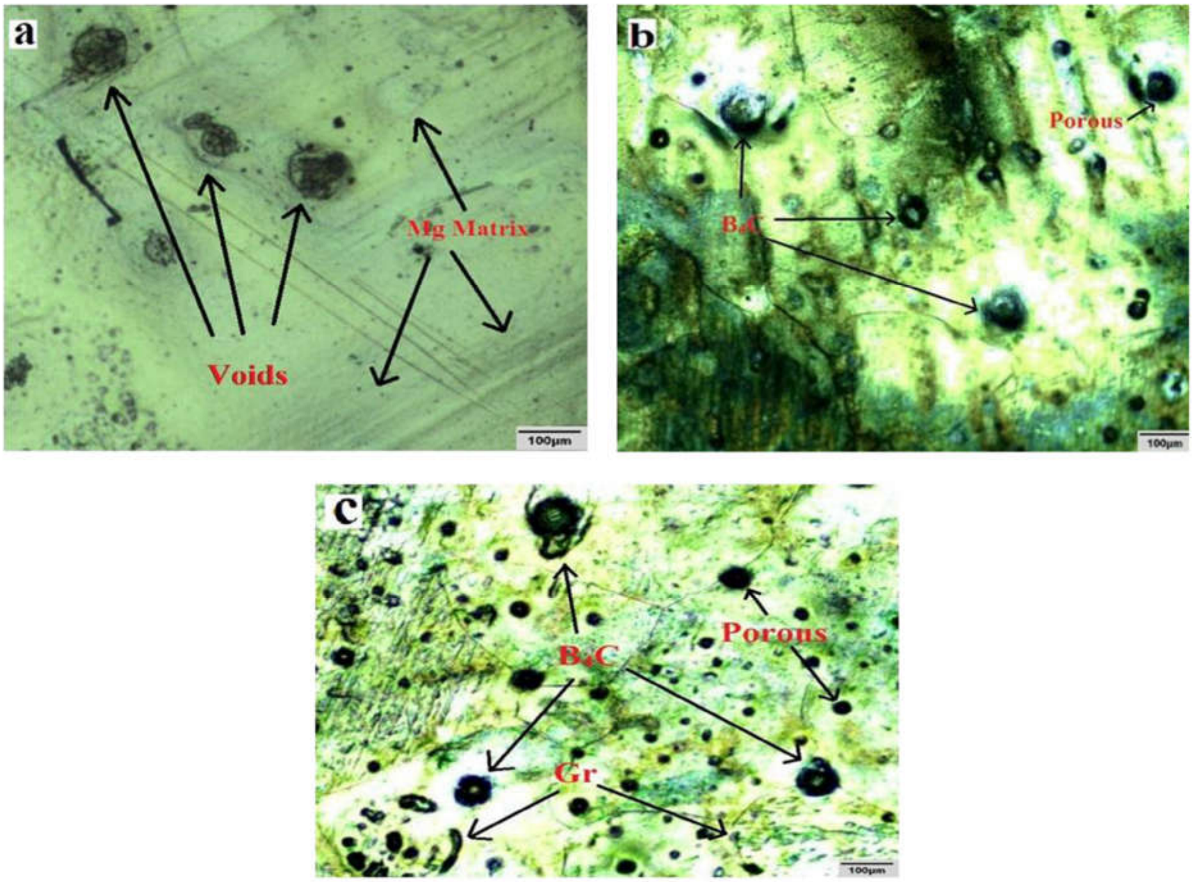

Fig.4. Optical micrographs of the produced composites: (a) AZ91D, (b) AZ91D/1.5% B_4C, (c) AZ91D/1.5% B_4C /1.5% Gr [5], reprinted with permission from I. Aatthisugan, A.R. Rose and D.S. Jebadurai // J. Magnes. Alloys 5(2017)20, under the CC BY-NC-ND 4.0 license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Latief and Sherif [18] studied the effect of graphite nanoplatelets particle (GnP) addition to pure aluminum. GnP were reinforced in four different weight percentage i.e. 0,1,3and 5wt% using powder metallurgy fabrication technique. It was investigated that Al-GnP (compression strength~148 Mpa, Hardness ~50 HV) composite with 5wt% Gnp have higher compression strength and hardness than that of pure aluminum alloy (compression strength ~180 Mpa, Hardness ~ 67.5 HV). Zhou et al. [19] fabricated CNT-LY12 composites using pressureless infiltration process and investigated the mechanical and tribological properties. Dry pin on disc tribometer was used for wear rate calculation and experiments were performed at 0.1571m/s speed and 30N load. It was noticed that upto 20 vol% reinforcement of CNT , wear rate of LY12-CNT aluminum composite was steadily decreased and this was due to strengthening and lubrication effect provide by presence of CNTs. Goh et al. [20] reinforced CNTs in 0.3,1.3,1.6 and 2wt% in pure Mg to form Mg-CNTs composites using disintegrated melt deposition (DMD) method and enhanced strength and ductility simultaneously. It was found that ductility ,UTS and Y.S of Mg-CNTs composite was superior than that of pure magnesium when CNTs was added upto 1.3wt% .However macrohardness of composite decreases with increase in CNTs content. Ghazaly et al. [21] fabricated AA2124-graphene composite with varying graphene content at 0.5,3,5wt% and compared the mechanical and tribological behavior of the composite with alloy.All composites were fabricated using powder metallurgy route. The results indicated that at 3wt% graphene addition there was a very smooth tribo layer present between sliding counterparts which reduced the wear rate of composite as compared to AA2124 aluminum alloy. Choi et al. [22] studied the mechanical and tribological behavior of Al-MWCNTs composites fabricated using powder metallurgy technique. It was demonstrated that with 4.5 wt% addition of MWCNTs in aluminum strength and wear resistance of aluminum was increased. The maim wear mechanism of was micro-ploughing and delamination. Das and Harikar [23] fabricated magnesium hybrid composite reinforced with GnP and SiC nano particles using ball milling and spark plasma sintering. They alos studied the mechanical and tribological properties of fabricated hybrid composites. It was demonstrated that magnesium hybrid composite with 2wt% of reinforcement exhibited superior hardness and wear properties than that of magnesium base matrix. The details of mechanical and tribological properties of aluminum and magnesium MMCs are illustrated in table 3 below.

Table3: Mechanical and tribological properties of carbonous material reinforced Aluminum and magnesium MMCs

REINFORCEMENT	MATRIX	FABRICATION PROCESS	MATRIX PROPERTIES	COMPOSITES PROPERTIES	Ref.
B_4C and GRAPHITE	AZ91D	STIR CASTING	HARDNESS ~20.5BHN UTS ~62.1 MPa WEIGHT LOSS 0.030g	HARDNESS ~22.5 UTS~86.3MPa WEIGHT LOSS 0.022g	[5]
CU COATED CNFS (0.76 wt%)	A7XXX ALLOY	MELT STIRRING METHOD	Y.S ~269.51 UTS ~313.09MPa HARDNESS ~97.7 HV	Y.S ~356.79 MPA UTS ~461 MPa HARDNESS ~119.64 HV	[17]
GRAPHITE NANO PALTELETS (5wt%)	ALUMINUM	POWDER METALLURGY	COMPRESSION STRENGTH ~148 MPa HARDNESS ~50 HV	COMPRESSION STRENGTH ~180 MPa HARDNESS ~ 67.5 HV	[18]
MWCNT (20 vol.%)	ALUMINUM	PRESSURELESS INFILTRATION	COF ~0.146 WEAR RATE (10 -2mg.m -1) ~1.34	COF ~0.105 WEAR RATE (10 -2mg.m -1) ~0.97	[19]

CNT (2wt%)	MAGNESIUM	DISINTEGRATED MELT DEPOSITION	Y.S 1 ~26 MPa UTS ~192 MPa	Y.S 1 ~40MPa UTS ~210MPa	[20]
NANO GRAPHENE(3wt%)	AA2124	POWDER METALLURGY	WEIGHT LOSS ~4mg WEAR RATE ~ 0.18 (mm3/Nm)* 10-4	WEIGHT LOSS ~2.3mg WEAR RATE ~0.059 (mm3/Nm)* 10-4	[21]
CNT (4.5wt%)	ALUMINUM	HOT MILLING	COF ~0.500 WEAR LOSS 1 ~80mg	COF ~0.078 WEAR LOSS ~40mg	[22]
NANO GRAPHENE (2 vol%)	MAGNESIUM	BALL MILLING AND SPARK PLASMA SINTERING	WEAR RATE (mm3/Nm)*10-11 ~1.107 HARDNESS ~48 HV	WEAR RATE (mm3/Nm)*10-11 ~ 0.880 HARDNESS ~63 HV	[23]

4. Conculsions

1. The carbonous nanomaterials have attracted great attention as the reinforcements for metals and their alloys to form lightweight nanocomposites for structural engineering and functional device applications .
2. The reinforcement of carbonous nanomaterials up to certain limit increases the mechanical and tribological properties of matrix.
3. Superior mechanical and tribological properties of MMNCs reinforced by carbon nanomaterials is due to metallurgical factors, such as Halle Petch effect by grain size refinement, Orowan looping and dislocation generation resulting from thermal mismatch between the matrix and reinforcements.
4. The significant decrease in COF and wear rate is due to formation of a lubricant film between the contact surfaces because of presence of carbon-based nano solid lubricant in MMNCs.
5. The reported results in the literature revealed that small amounts of graphene sheet and graphene nanoplatelet additions improve the tensile strength, hardness and wear resistance of resulting composites significantly.

6. The mechanical and physical properties of metal–matrix nanocomposites are largely controlled by several parameters such as the properties of the matrix, dispersion of the reinforcing phase, interfacial bonding and the processing method employed.
7. Carbonaceous nanomaterials are not wetted properly by the metal matrix during the composite fabrication. Therefore, coating carbon nanomaterials with copper, nickel or chromium can improve their compatibility and wettability.
8. To achieve favorable properties carbonous materials should be dispersed uniformly and not agglomerated in the matrix.

5. References

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