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Metal Matrix Nano-Composite Reinforced by Graphene- A Review

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Abstract: *Graphene has exceptionalpropertieslike high strength, greatelectrical and thermal conductivitywhichmakeit an idealreinforcement formaking a composite material. But development of advancedmaterialslike new metal matrix nano-composites for the enhancement of thermal, electrical and mechanicalpropertiesis a priority for numerous industries because of the rapidprogress of technology in recentyears. The researchwork on metal matrix nano-composite reinforced by graphene willbesummarized in thisreviewpaper.*
Keywords: *composite, graphene, mechanical, metal matrix, thermal*

I. Introduction

A composite material is a combination of two or more different materials that results in a superior (often stronger) product. Metal matrix composites (MMC) is composite material with minimum two constituents, out of which one is a metal and other may be different or another metal or material. Metal matrix composites are made by diffusing a reinforcing material into the base metal matrix [1]. Graphene metal matrix nano-composites has wide applications in marine, thermal management material, chemical sensors, and high level of stiffness, strength and good corrosion resistance.

1.1 Graphene

Graphene is an allotrope of carbon.Graphene is produced by combined effect of modified chemical and CVD method with multiple point of quality checks. It has been produced unintentionally in a small quantities for centuries through the use of pencil and other similar graphite application. It was observed originally in electron microscope in 1962, but it was studied only while supported on metal surface. The material was later rediscovered, isolated and characterized in 2004 by Andre Geim and Konstantin Novoselov [2] at the University of Manchester. Research was informed by existing theoretical description of its composition, structure and properties.

Table.1 Physical properties of graphene

Color	Black Powder
Purity	>99%
Number of layer	3-6 layer
Young's Modulus	130 GPa
Thermal Conductivity	5000W/mK
Electrical Conductivity	10×10^7 Siemens/M

Fig. 1 (a) Graphene powder

II. Literature Overview

Depending upon the manufacturing process literature review of various metal matrix reinforced by graphene is done.

2.1 Casting

Table 2. Casting

Base Metal	Reinforcement (wt. %)	Testing	ResultsStrength (MPa)	Reference
Magnesium(Mg)	0-0.3	Tensile Test	TS 136-221	[3]
Aluminium(Al)	0.2-0.4	Tensile Test	TS 146.2-173	[4]
Cu-Ti	1.5	Tensile Test	TS 175.23	[5]
MC Nylon-6	0.5-12	Tensile Test	TS 82.94-92.92	[6]
Copper(Cu)	1.96	Tensile Test	TS 280	[7]

Miao Wang, Yu Zhao and their colleagues [3] have attempted to improve the dispersibility, interfacing wettability and mechanical properties of graphene/magnesium composites by an in-situ reaction wetting process. Significant improvement of yield strength, hardness and good ductility can be achieved in the composites.Zhao W., Fan Y., Feng X. and their colleagues [4] synthesized few-layer graphene (FLG) platelets which were in between thin Al_2O_3 amorphous layer by spark plasma sintering. The results were increased strength of FLG/Al which was proportional to the FLG volume fraction up to ~0.2vol%.Z. Hu, G. Tong, D. Lin, C. Chenand others[5] reported the interfaces design strategy by matrix-alloying with Ti for in-situ interfacing carbide formation in reduce graphene oxide (RGO/CuTi) composites.Chengjie Li, Meng Xiang, Lin Ye [6] used the monomer casting nylon-6 (MC PA6)/graphene (GN) which was in-situ synthesized by incorporating of polyethylene glycol (PEG) as solid lubricant and compatibilzer. Addition of 0.5 wt% GN enhancement 12% increase in tensile strength, 75% reducing in specific wear rate. Adding 0.7 wt% GN reducing in friction coefficient.Ke Chu, Fan Wang, Xiao-hu Wang, Yu-biao Li, Zhaog-rongGeng, Da-jian Huang, Hu Zhang [7] used nano-plates graphene with copper composites with highly aligned GNPs by a vacuum filtration method by spark plasma sintering. These composites demonstrated that highly alignedgraphene network could indeed achieve the remarkable in plane. Enhancement in graphene/metal composites and resulting composites find application in electronic packaging that requires efficient directional heat transfer.

2.2 Spark Plasma Sintering

Table 3. Spark Plasma Sintering

Base Metal	Reinforcement (wt%)	Testing	Results Strength (MPa)	Reference
Inconel 718	0.25	Without HT WithHT	YS 530 YS 774.77	[8]
Copper(Cu)	0.1-0.3	UTM	TS 183-172	[9]
Titanium (Ti)	0.7	Tensile Test	TS 440	[10]
Copper (Cu)	1	Friction Test	0.35±0.03 20% lower	[11]

Shuan Ma, Yanjie Yang, Ang Li, Shiqi Zhou,Lan Shi, Shaolan Wang, Mabao Liu [8] found that metal matrix of nickel-base super alloy with graphene results in excellent mechanical properties in aircraft and aerospace. They used spark plasma sintering and carried out different test like SEM, MTS servo hydraulic testing machine. In these processes, mechanical properties of composite increases with temperature.Guosen Shao, Ping Liu, KeZhang, Wei Li,Xiaohong Chen, Fengcang Ma [9] prepared GNPs/Cu composite powder and the bulk GPNs/Cu composites were synthesized by spark plasma sintering with varying GNPs content. They found that the Cu matrix have dispersed the GNPs successfully and have maintained the structural integrity of graphene. Also, it has achieved the shape compatibility and size compatibility. The result were surprising. First the mechanical properties of GNPs/Cu composites increased and then decreased with increasing GNPs content. The highest performance was achieved when the volume of GNPs was 0.2wt%.Jian Liu, Mingxia Wu, Yi Yong, Xaixue Yan, Kyle Jianng. [10] did a research on GPL-reinforced titanium composite using spark plasma sintering. It was found that GPL was distributed in Ti matrix homogeneously and it is light in weight which can be used in various application.GPL/Ti composites present higher yield strength and bettercompressive performance than the pure Ti samples.Shao Yin, Zhao Zhang, Emmanuel J. Ekoi, Jing Jing Wong, Denis P. Dowling, Valeria Nicolosi, Rocco Lupoi [11] in 2017 applied cold spray to produce GNPs reinforced MMC coating. The obtained results show that copper includes GNPs completely. Also, no agglomeration of GNPs, phase change and oxidation were discoverd during the coating fabrication process. This offers great feasibility of this method to fabricated high quality GNPs reinforced MMC. The friction test shows that the GNPs reinforcement offers graphene rich lubricating film on worn surface which reduces the frictional coefficient by 20% when compared with the cold sprayed pure copper coating. Also, the cold sprayed MMC showed lower coefficient than spark plasma sintered MMC under same GNPs content.

2.3 Powder Metallurgy

Table 4. Powder Metallurgy

Base Metal	(%) ofMetal Base metal- Graphene	Test	Conclusion	Reference
Al_2O_3nanoparticles (NPs) and graphene nanoplatelets (GNPs)	None Al_2O-1.0 3.0 5.0 GNPs-0.1 0.5 1.0	Annealing Hours (t) (0) (3) 92.48±45 87.28±0.80 96.40±0.74 91.32±0.89 94.72±0.26 83.48 ± 0.49 101.0±0.33 91.24±0.37 86.44±1.24 - 87.10±1.02 87.48±0.44 86.08±0.58 -	Grain boundary strengthening and solute strengthening seemto account forthe strength inAl-GNP MMNCs.	[12]
Magnesiumwith addition of Aluminiumand Graphene	Mg Mg-0.5Al 0.18GNP Mg-1.0Al-0.18GNP Mg-1.5Al-0.18GNP	YS-162±5VH- 41±4 YS-173±4VH- 55±2 YS-190±5VH-58±3.5 YS-209±4VH-60±3	The best improvement was achieved with 1wt.% Al (Mg-1.0Al-0.18GNPs)	[13]
Investigation sinteringmode on various propertiesof copper-graphene metalmatrix composite	Pure copper Cu-0.9Vol%Gn Cu-1.8Vol%Gn Cu-2.7Vol%Gn Cu-3.6Vol%Gn	(Sinteringmode)HV100 ConventionalMicrowave 43±2.6 46±2.8 45±2 52±2 56±2.260±2 68±1.8 74±2.2 82±3 89±2.8	Copper-graphene composites exhibited 38 excellentwear resistance due to higher hardness and excellent lubricating natureof graphene.	[14]
Copper-graphene composites exhibited 38	Pure Mg	YS (MPA) VH 187±4 57.5±2	Yield and tensile strength is increased	[15]
Excellentwear resistance due to higher hardness and excellent lubricatingnature.	Mg/0.3wt% GNPs	197±3.168.5±2	Investigate the surface morphology, elemental percentage composition.	[16]
Titanium-Graphene (Ti-Gr)	Gr-2.5%- 7.5%	Laser SinteringSEM XRD EDS	UniformlyNano-Composite Hardness Increases DifferentCrystalStructure Uniformlynano-composite	[17]
Silver	Gr-sheet(length 350A)	Solidification	Good Wettability	[18]
Aluminium-Graphene	Gr-Only3Wt%	XRD	Improve Mech. Property.	[19]
MG-AL-GR	Mg-0.5Al-1 Gr-0.18% Mg-1 Al-1 Gr-0.18% Mg-1.5Al-1 Gr-0.18%	UTS(MPa)230 YS (MPa)173 Failure strain(%) 10.7 UTS(MPa)254 YS(MPa)190 Failure strain (%) 15.5 UTS(MPa) 268 YS(MPa)209 Failurestrain(%) 12.7	Increased Mechanical, Thermal and Electrical Properties.	[20]

MeysamTabandeh-Khorshid, J.B. Ferguson, Benjamin F. Schultz, Chang-Soo Kim, Kyu Cho and Pradeep K. Rohatgi [12] used powder metallurgy as a processing method to synthesize ultrafine and nano-metrix grain size alloy and composites. In previous work, nano crystalline (NC) metal matrix nano composites (MMNC) has cryomilling technique with liquid nitrogen. Pure NC-Al was reinforced with changing concentration of Al_20_3particles. As a result I) grain boundary counts for the strength of the Al-Al_2-O_3 MMC, II) grain boundaries solute strengthening accounts for the strength in Al-GNPs metal matrix Nano composites.Muhammad Rashad,Fusheng Pan, Aitao Tang, Muhammad Asif [13] synthesized Mg-Al-GNPs composites using semi powder metallurgy method which is followed by hot extrusion. The result showed compelling improvement in tensile strength. The obtained results were better than other previous research of Mg-Al-CNTs composites. The yieldstrength, ultimate tensile strength, failure strain (%) andVicker's hardness is increased by increasing Al-GNPs content. But when the Al content exceeds over 1.0 wt%, the failure strain starts to decrease.C.Ayyappadas, A.Muthuchamy, A. Raja Annamalai, Dinesh K. Agrawal [14] fabricated copper composites with varying amount of graphene particles by microwave and conventional sintering processes. The results were increased mechanical and electrical properties of microwave sintered composites as compared to conventionally sintered composites.Kai Fu, Xiang Zhang and others [15] have successfully fabricated GNs reinforced nickel matrix composites for improving mechanical properties. The results included enhanced mechanical properties of the composites; mainly with 1.0 vol% GNs, the yield strength and tensile strength increased by ~188.4% and ~26.0% to 474 MPa and 546 MPa respectively.Muhammad Rashad, Fusheng Pan, Aitao Tang, Muhammad Asif, Jun Gou, Jia She and others [16] used semi-powder metallurgy method to fabricate Mg-GNP (Mg/0.3 wt% GNP) composite for the first time. Additionally, for the enhancement of the thermal conductivity and to improve mechanical properties of Mg composite, they proposed GNPs as reinforcing filler. The XRD and EDS result confirmed the existence of GNP in the composite, whereas SEM result show the homogenous dispersion of GNPs in the Mg matrix. The addition of the GNPs increased the strength of the Mg upto 238 Mpa in tension.Zengrong Hu, Feng Chen, JialeXu, Zhenwu Ma and others [17] used graphene reinforced titanium prepared by laser sintering of the mixture of PVA bonding graphene sheets and titanium powders. Microstructures and components of the nanocomposite were studied by SEM, XRD, EDS and Raman spectroscopy. As a result, hardness measurement show that lazer sintered Ti-Gr nanocomposites achieved more than 2 fold Vicker's hardness value of barely sintered Ti. But the measuredmechanical results were obviously below the calculated results, which were explained from two aspects: the defects caused by laser sintering which reduced the intrinsic properties of graphene and the distribution of graphene in the Ti matrix.Sunil Kumar, Suchandan K. Das, Sudip K. Pattanayek[18] have stated that solidification and organising of silver nano particle in region between graphene sheet show various application in biomedical, electro chemical, coating material, catalyst MMNCs. Studies of atomic behaviour of solidification silver NPs show liquid crystalline phase at a temp. T=1030+ 25 k as a result silver nano particles shows good wettability over a graphene sheet and depits phase transition higher temperature compare to lower interaction potential energy. Prashantha Kumar H. G, S. Prabhakaran, AnthonyXavior M., S.Kalanathan, Dong Lin, Pratik Shukla, Vijay K. Vasudeven [19] studied the interlocked nanolaminated architecture of graphene-reinforced aluminum alloynano composition by lesser shock peening. From this re-nucleation to obtain metallic grains. Layer this location look formation the nano composition. in during experiment due to this consequently, enhancement in lower hardness, tensile strength wettability characteristic and properties due this composition material used sport material, automobile parts and bio-implant application. AbdoolahSaboori, MeharanDadkhah, PaoloFino, MatteoPavese [20] synthesized the Mg-Al graphene nano particles by powder metallurgy method. The GNPs kept constant (0.18%). Al content changes from (0.5% to 1.5%). Improvement was achieved by 1% wt of Al (Mg-1.0, Al-0.18 GNPs) as mechanical strength of composites were better than Mg-Al-GNTs and Mg-ceramic composites.

III. Conclusion

From the research, some properties such as mechanical characteristics, and thermal and electrical conductivities can be improved by introducing GNPs into metallic matrix. But it is also found that the content of graphene, graphene dispersion, and interfacial bonding between graphene and metallic matrix decides the improvements in thermal and electrical conductivities and mechanical properties. Lower graphene content causes improvement in the properties and higher graphene content deteriorates them. This is mainly due to the formation of graphene agglomerate. Thus it can be concluded that though there are a lot of challenges present in the MMNCs fabrication reinforced by GNPs, it will be possible to synthesize newer metal matrix nano-composites from chromium or tungsten with improved thermal, electrical and mechanical properties.

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