IOSR Journal of Engineering (IOSR JEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
PP 17-22

A Review on Tribological properties of Metal Matrix Nano Composite

Noorul Ameen[1], A. A. Shaikh[2], Sharique Ather[3], Aakif Anjum[4]
[1,3,4](Department of Mechanical Engineering, MMANTC, Mansoora, Malegaon, India)
[2](Department of Mechanical Engineering, SVNIT, Surat, India)

Abstract: *Metal Matrix Nano Composite (MMNC) shows great ability to replace conventional Metal alloys and Metal Matrix Composite due to their extraordinary properties. In this research paper effect of nano fillers on tribological properties of metal matrix are reviewed. Past research clearly indicates that addition of nano particles into metal matrix or alloy improves tribological properties in terms of reduction in wear rate and decrease in Co- efficient of friction. Addition of graphene, nano graphite and carbon and tube formation of solid lubricant layer which cause improved wear resistance while other nano fillers (Al2O3,SiC,TiC, WC) cause improvement in micro hardness and Orowan strengthening mechanism to reduce wear and friction of composite materials. Nano particle reinforced metal matrix composites hence proved to be ideal for various tribological applications.*

Keywords: *Carbon Nano Tubes (CNT), Metal Matrix Nan composite (MMNC), Multi Layer Graphene (MLG), tribological properties, wear loss*

I. Introduction

Composite are the combination of two or more materials exhibits the properties which can note be achieved by any discrete material. The constituent of composite are different in characteristics, composition and sometimes in form. They differ from alloys since in composite material the individual components retain their own properties so as to take the advantage of it to get material with improved properties. One can defined composite material as These are the materials which are artificially made having at least two species with well defined interface exhibit at least one property which does not possessed by individual constituent and whose properties much dependant on volume percentage of ingredient [1,2]. Composite may be classified as Particulate Composite Materials (PCM) and Fibrous Composite Materials (FCM) based on the filler material type or reinforcement. Particulate Composite Materials (PCM) are one which having reinforcement in the form of particle or platelets. In Fibrous Composite Materials (FCM) the filler material are in the form of fiber i.e. having length much greater than its cross section dimension. Composite also may be classified on the basis of type of matrix as Metal Matrix Composite (MMC) which are having metal as a large constituent, Polymer Matrix Composite (PMC) in which fillers are mixed in polymer matrix (resin) and Ceramic Matrix Composite (CMC) in which reinforcement is done in ceramic matrix [1,2]. When the size of filler material is in the range of nano size then Nano composite materials are come to existence. Now a day's metal matrix nano composite turn out to be excellent alternative to overcome limitations of MMC [1,2].

As the aim of composite material to produce such materials which are having improved characteristics than individual material , in this study the objective is enhancement of tribological properties by reinforcing nano sized material in metal matrix. This paper discussed the various metal matrix nano composite materials and effect of nano particle reinforcement on tribological properties.[3]

II. Graphene Reinforced MMNC

Qingshuai Zhu et al prepared Ni_3Al matrix composites with 1.5 wt% graphene nanoplatelets (GNPs) by Spark Plasma Sintering (SPS). Dry sliding tribological tests were performed under different loads and investigated fric- tion and wear properties. The results show that with increase in load the value of friction coefficient decreases. The reason behind that in sliding wear process accumulation of friction heat causing formation of two types of layers i.e. Ultrafine layer(UL) and a Matrix Refinement Layer (MRL).Due to UL the coefficient of friction an wear rate decreases while MRL causes the improvement of wear resistance [4] Yecheng Xiao et al also prepared the composite material by addition of graphene particles with 1.5% in NiAl matrix using Spark Plasma Sintering. Tribological test is carried out on ball on disk tribometer at different loads. Their research shows that in NiAl alloy with graphene reinforcement, the friction coefficient reduces and smoother curve obtained with increase in load while slight more wear rate occurs with increasing load. But NiAl alloy without graphene shows more coefficient of friction and much higher wear rate than graphene reinforced alloy for the same condition [6]. Fanyan Chen et al. [7] reinforced graphene nanoplatlets(GNPs) in Cu matrix.via molecular level mixing process and spark plasma sintering process. Study reveals the effect of graphene content on tribological performance of Cu/GNPs composites. Addition of small amount of GNPs does not much affect the anti-friction property. The coefficient of friction 0.4 vol% is about 60% lower than the pure copper. [7].GNPs also reinforced with aluminum matrix by powder metallurgy method and tribological behavior of the composite found out by Meysam Tabandeh-Khorshid et al[5] wear and friction analysis is done with pure Aluminum, composite with 0.1 wt % GNPs and composite with 1wt% GNPs on pin on disk apparatus. The outcomes show that the COF reduce with increasing loads in all cases with same pattern. Also rate of decrease in COF is more in higher loads. Composite with 1 wt. % shows significant decrease in COF. Decrease in COF is due to formation of graphene film. It also shows that wear rate is more with increasing load .0.1 wt. % of GNPs shows minimum wear rate from all samples.[8] H. G. Prashantha Kumar et al synthesized Al 6061-Gr (0–1.2 wt%) mixing Al 6061 alloy particles and graphene using ultrasonic liquid processor followed by hot compaction. Composite samples were tested for different load and sliding speed. Results show that with increase in Gr content, the value of COF and wear loss decreaseThe values of COF and wear loss are found optimum at 0.4 and 0.6 wt% [9].Jie Yao et al worked on NiAl composite and reinforcement of 1.5 wt % multi layer Graphene (MLG) and 5wt%WS2. The composite were synthesized by Spark Plasma Sintering. The results showed that the tribological properties of NiAl composites were obviously improved after adding WS2 and MLG. About 50% reduction in COF and 90% decrease in wear rate is observed after reinforce- ment. Microstructure analysis shows that formation of layer of MLG and WS2 due to deformation and flow in the sliding wear process. A research on Mg reinforced with Gr synthesized by SPS done by Aniruddha Das et al[12] shows that the wear rate decreases continuously with increasing GNP content (0%, 1%, 2%,5% vol). There was not much variation of coefficient of friction for Mg and Mg-GNP (1 vol.% GNP). The Mg-GNP samples reinforced with 2vol % and 5 vol.% GNPs showed relatively lower coefficient of friction compared to pure Mg compacts.[12] In other research work done by Zengshi Xu et al Multi layer Graphene (MLG) filler is used in NiAl matrix as prepared by powder metallurgy and tribological test were carried out. The result shows about 50 % decrease in COF and 80% reduction in wear rate with addition of NiAl-MLG as compare to pure NiAl [13]

Chennakesava Reddy prepared AA4015/graphite metal matrix composites by stir casting process. An examination of wear rate between 10%, 20% and 30% graphite composites is done. The wear loss diminished with increasing volume % of graphite in Aluminum alloy. Of course, the high wear resistance of Al-graphite composites is because of graphite particles which work as solid lubricant as shown by micrographs of worn surface. Also well scattered graphite particle shows good wear resistance [15]. In other research work done by him he prepared another composite of alumunim alloy with graphite i.e AA6061/Graphite composite (10%, 20%, 30%) by stir casting and tribological behavior investigated. Wear test is carried out by pin on disc apparatus. The result indicates that wear rate was decreasing with increase in volume fraction of graphite in AA6061 alloy matrix [16]. Adalet Zeren investigated the effect of graphite particles on wear loss of Al-SiC composite. The sample was prepared by powder metallurgy route. The tribologcal test was carried out on pin on disc tribometer. Result indicates adding graphite to Al-SiC composites enhanced wear resistance. Al-SiC composites containing 6 weight percent graphite displayed better wear properties. Graphite addition more than 6 wt. % cause increase in wear loss. This is because of lamination of graphite particle [17].

III. Carbon Nanotube Reinforced MMNC

Leander Reineegart et al investigate the effect of CNT on tribological properties of Nickel. They have compared the tribological properties of Ni reinforced with CNT composite and Ni coated with CNT. The result indicates that in short term tribological experiment (200 sliding cycles), the CNT coated composite and CNT reinforced composite shows reduction in COF. But there is no significant difference between both the samples in the values of COF. In contrast to that in long term tribological experiment (20.000 sliding cycles), it could be seen that the wear decrease of the CNT-covered composite just goes on for the initial 3000 cycles after which the COF approaches the estimation of the reference. This can be clarified by the continuous removal of CNTs from the contact zone. As opposed to that, the CNT-reinforced composite shows an articulated friction decrease over the whole 20.000 sliding cycles, which can be credited basically to the consistent supply of CNT to contact zone[19]. K. R. Padmavathi et al prepared the hybrid composite of Aluminum alloy with SicC and MWCNT by stir casting. The wear and friction test was performed on pin on disc apparatus. Result shows that for all values of the applied load, specific wear rate decreases with the increase of the % of MWCNT [21]. In another research done by Ali Alizadeh et al , aluminum based hybrid composite reinforced with boron carbide (B4C) and carbon nanotubes (CNTs) was produced by powder metallurgy method. The results indicates that addition of 5vol.%CNT to Al 5083 matrix decrease alloy wear resistance and creep strength which is mainly due to CNT agglomeration and segregation at grain boundaries but CNT in addition to boron carbide significantly increase the wear resistance[22].

IV. Alumina Reinforced MMNC

R. Surendran et al. done research on enhancement of Wear Properties Aluminum Alloy with Addition of Nano Alumina by stir casting process. The result indicates that there is significant decrease in wear rate with addition of nano alumina. The composition of 97.5%LM 25 + 2.5% nano Al2O3 shows greater wear resistance compare to all samples[24]. In another research done by N. Hosseini et al. tribological properties of aluminum alloy reinforced with alumina investigated. There result of research clearly indicates that the size of nano particle affect the wear rate as smallest size particle exhibit the lowest wear rate [25]. Xiao-song JIANG et al. synthe- sized Alumina reinforced aluminum matrix composites (Al−5%Si−Al2O3) by powder metallurgy and wear and friction properties were found. With the load increasing, the wear rate also increase due Al2O3 particles produce some shedding traces and grooves on the surface. While the increase in speed causes reduction in wear rate due to oxide layer formation at high temperature [26] . In another study done by Y. Mazaheri et al. with aluminum alloy reinforced with nano alumina (A356/Al2O3) shows that wear rate and COF are considerably less in nano composite as compare to micro composite and unenforced Al alloy. Improved wear resistance of surface micro and nano composite layers is Due to more micro hardness caused by fine scattered nano particles [28]. M. Karbalaei Akbari prepared Aluminum alloy (A356), was used as matrix material reinforced with Nano-Al2O3 powders bystir casting method. Pin-on-disc testing machine is used for dry sliding wear test. Results show that small amount of nano-Al2O3 addition gives improved wear resistance in A356 alloy due to gathering of Al2O3 particles on the surface which resists wear [29].

V. Boron Carbide (B4C) Reinforced MMNC

A. Chennakesava Reddy synthesized the aluminum alloy reinforced with nano sized boron carbide (B4C) by stir casting process. Analysis is done by Taguchi method and ANNOVA. Result show that the wear resistance increments with increment of vol% B4C nanoparticles in AA1100 nano composite due to high hardness of B4C nano particles. Also the rate of wear increases as value of load and sliding distance increases [30]. In this paper by Alireza Abdollah et al. tribological behavior of nano structured Al2024 alloy reinforced with B4C nanoparticles produced by mechanical milling and hot extrusion were investigated. Result indicates significant decrease in wear loss when the alloy is reinforced with nano B4C particles. The better wear resistance of Al-B4C composite than Al composite B4C particles increases strength, hardness and thermal stability of aluminum based alloy which improves tribological properties [31]. Comparison of effect of micro sized and nano size B4C on mechanical properties also done by R. Harichan- dran et al. The micro and nano-sized B4C particles were added to the Aluminum matrix at proportions of 2, 4, 6, 8 and 10% by weight. The result shows decrease in wear loss by incorporating nano and micro sized B4C particles. The nanocomposites were more wear safe than the microcomposites up to 8 wt.% of B4C. The expansion in the wear obstruction of the nanocomposite enhanced the hardness and reinforcing system. The wear conduct uncovers that the wear rate and coefficient of friction are inversely connected with the boron carbide molecule content. The SEM examination uncovered that the arrangement of a mechanically blended layer is a key factor in controlling the wear conduct of the micro and nanocomposites [32]. A. Alizadeh et al. investigated wear behavior of Al–2 wt.% Cu alloy composites reinforced by B4C nanoparticles and fabricated by mechanical milling and hot extru- sion. The wear rate of unreinforced composite is more than the composite reinforced with nano B4C particles as evident from the test result and it is due to improved hardness of later [33]. A. Devaraju et al evaluated wear properties of Al reinforced Boron carbide nano composite. The synthesis of composite is done by stir casting process. The outcome of the research shows wear rate continuously decreases as 5% of reinforcement increases. Optimum percentage of reinforcement is 7.5% reinforcement of boron carbide (A7.5) which has lowest wear rate [34].

VI. Silicon Carbide Nanoparticles (SIC) Reinfoced MMNC

SiC have low electrical resistance and high chemical resistance. In the Mohs-hardness scale, SiC hardness is between corundum and diamond. That property is used to increase the wear properties of certain composite. H.R. Akramifard et al. reinforced SiC nanoparticles with copper matrix and wear properties has been diag- nosed. Result shows that on reinforcement of SiC nanoparticles the wear rate decreased the reason which were shown are fine dispersion of SiC particles Orowan strengthening mechanism and microhrdness enhancement [36]. SiC particles also reinforced with zinc–aluminum alloy i.e. ZA-27 by stir casting method. The wear analysis was done by Taguchi design of experiment. According to result of Taguchi experiment the filler content found to be most affecting factor on wear properties of ZA-27 composite filled with SiC particles [37]. G.H. Majzoobi et al. prepared Al7075-SiC nanocomposit by hot dynamic compaction and tribological properties were investigated. The analysis shows that wear rate increased with increase of SiC content but micro hardness increases. The reason behind this is weak bonding between Al7075 and SiC particles during dynamic consolidation [38].

VII. Titanium Carbide (TiC) Nanoparticles Reinforced MMNC

Various researches has been done on TiC nanoparticles by considering its properties these have been used to improve the certain mechanical properties of metals. One of the research works on TiC reinforced AlSi10Mgdone by Dongdong Gu et al. and wear property is obtained after reinforcement. The composite is fabricated by Selective laser melting (SLM). Result shows that at Laser Energy per unit length (LEPUL) affects the wear performance. At 700 LEPUL J/m least COF and least wear rate obtained. Further increase in LEPUL again cause increase in COF and wear rate [39]. A. Lekatou et al. reinforced TiC(1% and 0.7%) particles in Al alloy the result indicate that addition of TiC particles significantly improves wear resistance. Adding 1.0 vol % TiC gives decrement of wear rate by factor of 2.2. Such outcome will be due to dispersion of particles causing strengthening [40]. In another research in which TiC particles were reinforced with Aluminum alloy (AA7075) and tribological properties were evaluated. The research evident that with increase in the TiC contents the wear resistance of TiC reinforced composite increase. Although addition of 10% TiC does not much affect the wear resistance. This is because at low percentage of reinforcement the composite shows adhesive wear after increasing % of reinforcement it turns into abrasive wear [41].

VIII. Tungsten Carbide (WC) Nanoparticles Reinforced MMNC

Manvandra Kumar Singh et al synthesized Copper based nano tungsten carbide (WC) composite by stir casting techniques and wear behavior was examined on pin on disc apparatus. Result shows that total weight reduction against the connected normal load of composites is low as correlation with both copper lattice and copper nano composite because of strain solidifying and soon introduction of harder tungsten carbide particles [43]. In another research done by M.R. Fernández et al. effect of WC is found out when reinforced with NiCrBSi alloy. The outcome shows that no direct relation can be obtained between COF and variation of wt% WC. Slight increase in COF occurs as % WC increased from 0% to 50 % but An unmistakable decrease in wear can be acknowledged as the WC particles increased. This decrease being exceptionally articulated from focuses above 30% [42]. Debalina Bhattacharjee et al. found out the effect of WC particles on tribological behavior of Iron. The composite was prepared by powder metallurgy with reinforcement of micro WC and nano WC. The result of sliding wear test shows that nano WC reinforcement shows lower COF in comparison with Micro composite and unreinforced iron. This is due to the micro sized particles from matrix are easy to remove during dry sliding test hence exhibit poor wear resistance [44].

IX. Conclusion

In above mentioned papers various fabrication methods were adopted for synthesis of Metal matrix nano composite and different nanoparticles were reinforced in metal matrix to evaluate tribological properties. From all the research it is evident that addition of nano fillers improves tribological properties.

From the review of above research papers one can conclude that,

- Addition of graphene significantly improves the tribological properties of metal but dispersion of graphene particles in metal matrix and filler percentage also plays a major role in deciding tribological properties.
- Other reinforcement Graphite and CNT also reduce COF and wear rate by formation of film causing wear reduction.
- Grsphene, Graphite and Carbon Nano Tubes may act as solid lubricant within the metal matrix.
- Nanoparticles of alumina and carbides (B4C, SiC,TiC, WC) enhance micro hardness and hence wear and friction properties.

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