Fabrication, Characterization and Tribological Studies on Aluminum Based Hybrid Metal Matrix Composites

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CERTIFICATE

This is to certify that the thesis entitled **"Fabrication, Characterization and Tribological studies on Aluminum based Hybrid Metal Matrix Composites"** being submitted by **Aniruddha Vinayak Muley** to the Indian Institute of Technology, Delhi for the award of **Doctor of Philosophy** is a record of original bonafide research work carried out by him under our guidance and supervision. In our opinion, the thesis has reached the standard of fulfilling the requirements of all the regulations related to the degree. The research report and results presented in this thesis have not been submitted, in part or in full, to any other university or institution for the award of any degree or diploma.

We certify that he has pursued the prescribed course of research.

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ABSTRACT

Aluminum matrix composites (AMCs) with their enhanced strength, improved stiffness, reduced density, improved abrasion and wear resistance offer better alternative to existing materials used for structural, non structural and functional applications. Commonly used reinforcement in AMCs are of micro level, however technological advancement in nano sciences makes it possible to use nano sized reinforcement in metal matrix composites and these are termed as Metal Matrix Nano Composites (MMNCs). 'Nanocomposites' were proposed by Niihara , a new material design concept where in second phase nano particles dispersed in matrix to enhance various properties of composite materials. In MMNCs, the reinforcement is in the nano meter rage (10^{-9} m) i.e. less than 100 nm which has interaction at interface due to its increased surface area, this leads to superior material properties. Nano sized reinforcements can significantly improve mechanical strength, creep resistance at elevated temperature, better machinability and higher fatigue life without affecting ductility. Improvement in the properties of MMCs is attributed to the hardening mechanism, fine particle size, uniform distribution, inter particle spacing and thermal stability at high temperature.

Hybrid composites can have engineering combination of two or more forms of reinforcement like fibers, short fibers, particulates, whiskers and nanotubes. It can have different materials as reinforcement like (SiC, Al_2O_3), (Graphite, SiC) and (Graphite, Al_2O_3) etc. e.g. Car engine block in which graphite and alumina are used in the form of particulates.There have been a very few studies available on aluminum (Al) based hybrid composites which consist of nano particles as reinforcement in hybrid form.Hybrid composites have improved properties compared to monolithic materials and single reinforcement micro particle composites.

The research work presented in the thesis is carried out with the objective to fabricate and characterize the aluminum based hybrid composite mechanically and tribologically. The hybrid composites are fabricated with LM6 (Al Si alloy) as a matrix and Al_2O_3, SiC as nano size reinforcement. Stir casting method is used to fabricate hybrid composites. Hybrid composites fabricated consist of 0.5, 1.0, 1.5 and 2.0 wt.% of nano particles in equal ratio. The composites are characterized by using density measurement, Vickers micro-hardness and tensile test to know its physical and mechanical properties. The difference in theoretical and actual density is less, which show the particles are distributed uniformly. The hardness and tensile strength of hybrid composites are increased with increased wt.% of nano particles. Optical microscopy, SEM and AFM techniques are used to know micro structure, particle distribution and particle morphology respectively. The particles are very small so could not be seen in micrographs obtained using optical microscopy. The SEM and AFM (2D and 3D) show the presence of nano particles and their distribution in hybrid composites. EDAX analysis is also carried out to confirm the presence of particle in composites. Pin on disc wear test is conducted to determine the tribological performance of hybrid composites. It is exhibited from the results that there is reduction in wear loss with increased wt. % of nano particles in hybrid composites. To further optimize tribological properties (Wear loss and Coefficient of friction) of hybrid composites, CCD (Central Composite Design) a scheme of statistical tool Design of Experiment (DOE) is used. Results exhibited that the hybrid composites have enhanced mechanical and tribological properties. Only small wt.% of nano reinforcement in hybrid form resulted in substantial improvement in properties of hybrid composites. Al based hybrid composites with nano size reinforcement have high potential to be used for different applications due to their enhanced mechanical and tribological properties.

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Abbreviations

Al	Aluminum
MMC	Metal Matrix Composites
AMC	Aluminum matrix composites
MMNC	Metal matrix nano composites
PM	Powder Metallurgy
CVD	Chemical vapour deposition
PVD	Physical vapour deposition
ECAP	Equal channel angular pressing
HPT	Hot pressure torsion
HIP	Hot isostatic pressing
HVOF	High velocity oxyfuel spraying
SPS	Spark plasma spraying
DIMOX	Direct melt oxidation
XD	Exothermic dispersion
SHS	Self propagating high temperature synthesis
CNT	Carbon nano tubes
MWCNT	Multiwall carbon nano tubes
SPD	Severe plastic deformation
FSP	Friction stir processing
FSWP	Friction stir welding process
DMD	Disintegrated melt deposition
SLS	Selective laser sintering
LOM	Laminated object manufacturing
SL	Stereo lithography
FDM	Fuse deposition modelling
3DP	3 D printing
UTS	Ultimate tensile strength

SEM	Scanning electron microscopy
TEM	Transmission electron microscopy
GNS	Graphenes nano sheets
CTE	Coefficient of thermal expansion
MML	Mechanically mixed layer
Al-Si alloy	Aluminum-Silicon alloy
AFM	Atomic Force Microscopy
EDAX	Energy dispersive X-ray
DOE	Design of Experiments
CCD	Central Composite Design
ANOVA	Analysis of Variance

Symbols

μ	**Coefficient of friction**
ρ	**Dislocation density**
ΔT	**Temperature difference**
Vv	**Volume fraction**
b	**Burger vector**
α	**Constant**
G	**Shear modulus**
d	**Size of reinforcement**
$\Delta\sigma_{dis}$	**Thermal expansion dislocation strengthening**
$\Delta\sigma_{gb}$	**Small sub grain strengthening**
Ky	**Material constant**
K	**constant**
$\Delta\sigma_{wh1}$	**Secondary dislocation strengthening due deformation at particle interface**
$\Delta\sigma_{wh2}$	**Secondary dislocation strengthening due geometrically necessary dislocation**
γ_{SV}	**Specific surface energy at solid/ vapour interface**
γ_{SL}	**Specific surface energy at solid/liquid interface**
γ_{LV}	**Specific surface energy at liquid / vapour interface**