Manufacturing of aluminium nano hybrid composites: a state of review

Manufacturing of aluminium nano hybrid composites: a state of review

P Madhukar[1], N Selvaraj[1], C S P Rao[1]

[1]Mechanical Engineering Department, National Institute of Technology, Warangal, Telangana, India-506004

Email: pmadhu88@gmail.com

Abstract. This paper gives the details of hybrid composites, their fabrication methods and evaluation of mechanical, tribological behaviour and machining characteristics. Investigations on the various aspects of Hybrid composites furnish several conclusions regarding the influence of various parameters on the performance of the composites. Mostly micro structures of the hybrid composites fabricated through casting routes have been found to be stable with the distribution of uniformed reinforce particles. therefore, the hybrid composites can be constructed with various combinations of reinforcements to carry out desirable mechanical properties. The density of Hybrid composites increases with increasing reinforcements such as SiC, TiC, B4C....etc, while incorporation of partial reinforcements like fly ash, mica, rice husk, etc. reduces the density of composites. The study also reports that the hybrid composites can be treated as a replacement for regular composite materials in different advanced applications.

1. Introduction

Materials required for the present world are stronger, lighter and cost effective. Present researchers are focusing to develop hybrid composites, which has good strength to weight ratio to meet the requirement. The main advantages[56] of Hybrid Composites over monolithic, alloys and composite materials were high strength to weight ratio, good corrosion/wear resistance, strength/stiffness, low thermal conductivity/coefficient of thermal expansion, light weight, Better impact and flexural properties Reduced overall cost of the composite. The example: aircraft as well as Automobile applications, where the fuel economy plays the key role.Hybrid composites consisting of one matrix and two or more reinforcement. These are bonded due to heterogeneous mixing of one or more particles reinforcement, which has been homogeneous phases at macro level and fabricated through various techniques such as powder metallurgy[3,5,6,19,26,30,33,40,52] route, stir casting[10,13,16,22-24,27,28,36,38,46-48], two step stir casting[41-43,34], squeeze casting[12,31] to aim the mechanical properties and tribological behavior: high specific strength, including stiffness, density, micro hardness, low coefficient of thermal expansion, high thermal resistance, good damping capacities, better wear resistance, and corrosion resistance

2. Classification of hybrid composites:

Normally composites are categorized into particle reinforced, fiber reinforced and the structural one. It is also classified based on matrix material such as polymer matrix composites(PMC), metal matrix composites(MMC) and ceramic matrix composites(CMC). Hybrid materials defined[53,54]as the mixtures of two or more materials with Atomic or molecular level of different materials with chemical-bonds between their different materials. Aluminum metal matrix[5-7,15,18,19,21-40] hybrid composite reinforced with silicon carbide, boron carbide, fly ash, Graphite, Si3N4 and Rice husk.Magnesium metal matrix[14,17,52] hybrid composite reinforced with silicon carbide, titanium carbide, boron carbide, molybdenum di-sulfide Copper metal matrix[3,50,51] hybrid composite reinforced with silicon carbide, boron carbide, titanium carbide. And other reinforced hybrid composites like fiber reinforcement[4] as well as fiber/metal hybrid laminates[1,2,12], The selection of reinforcement particles55 plays a major role in composites for incorporating high end properties. There are two important factors to be considered while choosing reinforcement particles for developing a composite. Firstly, the reinforcement particles should be stiffer and stronger than the material matrix to strengthen the composite and secondly, to obtain good crystal structure as well as interface bond between the matrix material and reinforcement particles

3. Properties of the material:

The Ultimate properties of the hybrid composites depend on reinforcement of individual nano particles properties selected and the metal matrix. Mechanical Properties the most common properties considered are ductility, strength, impact resistance, hardness, and fracture toughness. Mechanical properties[23,52,27,28,45,35,46] were improved with ceramic particles such as SiC, TiC, Alumina, B4N...etc and decreased by increases of Bamboo Leaf Ash(BLA), Fly Ash(FA), Rice Husk Ash(RHA), Mica.

The strengthening effect of composite material is degrading with increase in the size of reinforcement particles and inter-particle spacing is increasing with increase of reinforcement particle size, supported results shown in below

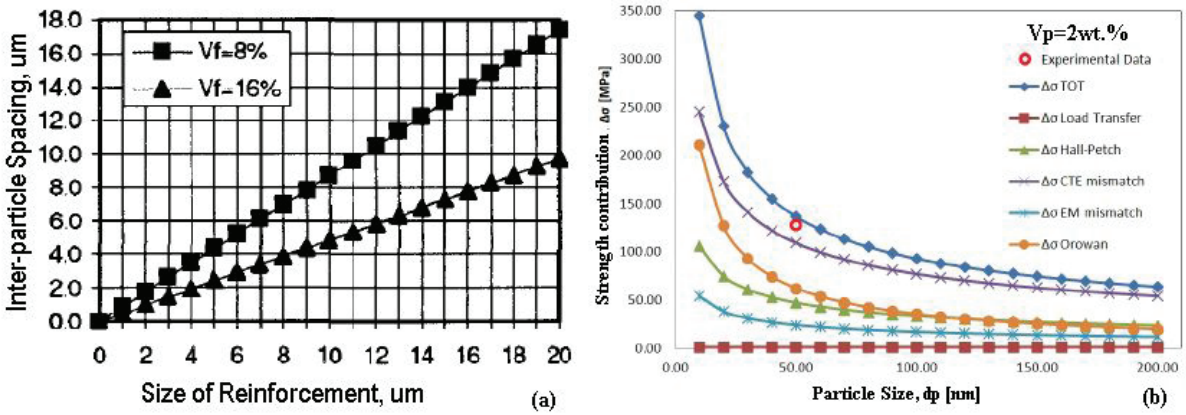

Figure 1. (a) Effect of reinforcement size and volume fraction on inter-particle spacing of reinforcement[57].(b) Effect of strengthening contributions and total resulting strengthening increment for a 2 wt.% Al2O3 reinforced Al matrix composite[58]

Tribological Properties: It is the study of interacting surfaces in relative motion,The tribological interactions of a solid surface are with interfacing materials and environment may result in material loss from the surface, tribological properties such as wear resistance[21,26,27,38-43,47,49] improved by increasing of Gr, Fly ash, Mica, Bamboo leaf ash, Rice husk ash, Fly ash...etc

Chemical Properties: Chemical interactions and reactions between the matrix and the reinforcement particles determined by the interface adhesion. With the correct resin selection as well as the construction of composites can withstand exposure. In general, higher chemical concentrations and temperatures result in lower durability and higher corrosion behavior[35,41-44] of composites. Corrosion resistance improved by increases of SiC, Mica, e-glass...etc

Physical Properties: The density of hybrid composites Increases with increases of ceramic reinforcements, while incorporation of partial reinforcements such as rice husk ash, fly ash, mica,.. etc. reduces the composites density[23,24,50,30,34,46,37,47].

4. Processing of hybrid composites:

Researchers were approached to manufacture the Hybrid Composites(HBCs) through various routes such as powder metallurgy(PM), stir casting, two step stir casting, squeeze casting and other processes were discussed below

4.1 Powder Metallurgy:

It's the method to prepare materials or composites from metal powers. This process can greatly avoid the yield losses in manufacturing components at lower costs. PM process consists three main steps are powder blending, die compression as well as sintering were showed in a schematic diagram. Research work done through this method to enhance the properties of composites, is presented here.

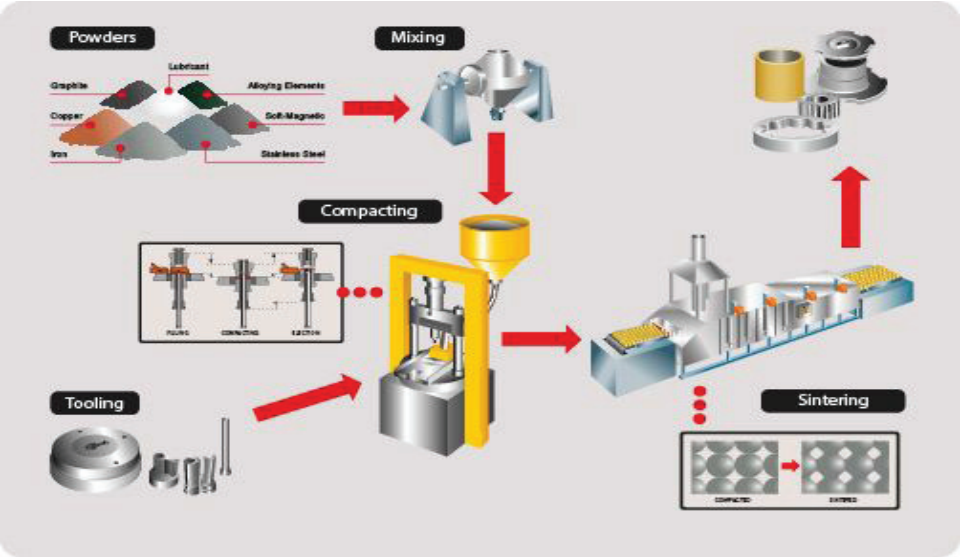

Figure 2. Schematic Diagram of Powder Metallurgy Technique (Google Image:http://www.ames-powder-metal.com/technology/powder-metal-manufacture-process/)

The fabrication of hybrid composite done through powder metallurgy route[3,5,6,19,26,30,33,40,52]D Nayak, et al.[3](2014) used the factorial method to analyze the tribological performance of Cu hybrid composite and reported the addition of Graphite-decreases hardness as well as adding of TiC increases hardness. While performing the wear test the weight loss of hybrid composite decreases up to some limit as the volume percentage of graphite increases. S Basavarajappa, et al.[5] fabricated Al2219/15SiC and Al2219/15SiC3Gr hybrid composite using Liquid Metallurgy route, reported inclusion of Graphite to Al/SiC particles reduces thrust force. Observed the feed rate significantly influencing on surface finish, thrust force as well as burr height. Drilling of Al2219/15SiC3Gr hybrid composite had poor surface finish when it compared to Al2219/15SiC composite due to pullout of graphite particles. Also identified that the surface roughness value decreases with increasing in cutting speed, increasing with increasing in feed rate And burr height reduced when hybrid composite drilled with carbide drill bit then coated carbide as shown in figure 3.

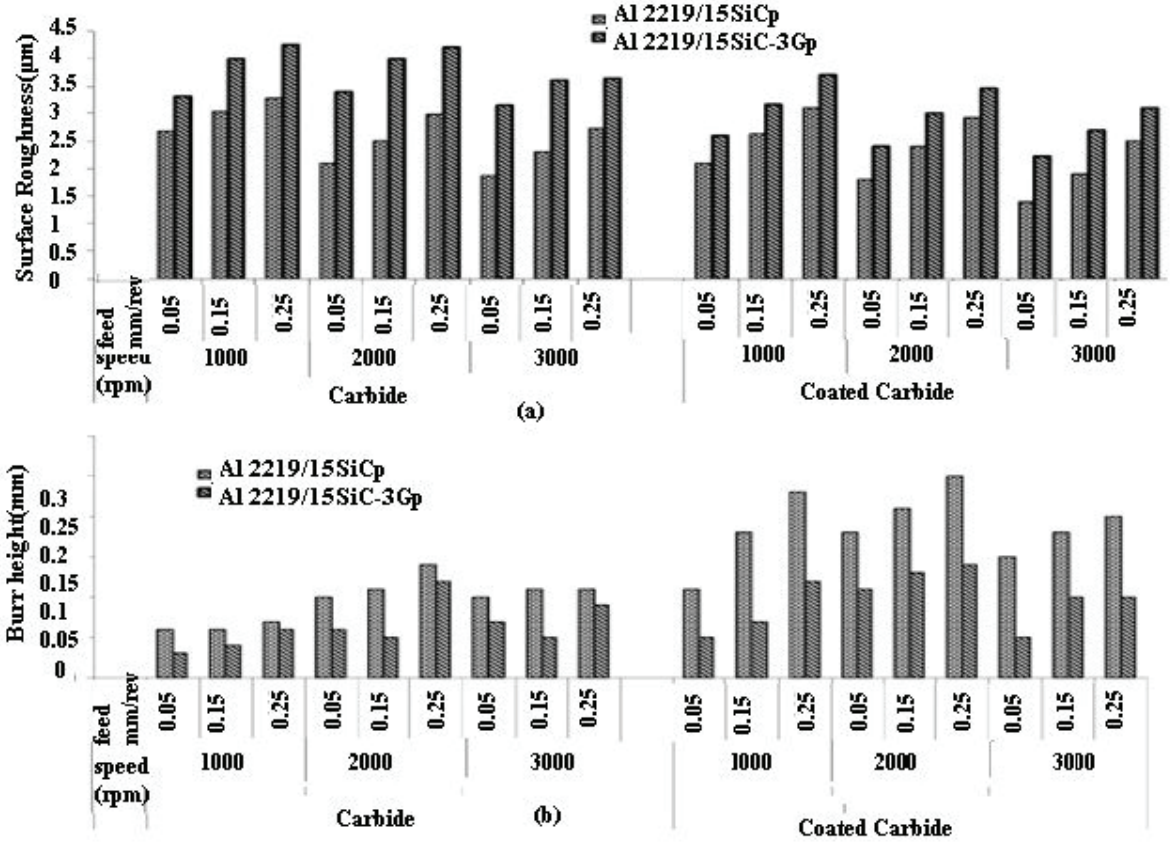

Figure 3. (a) Variation of surface roughness value for various speeds and feeds when machining of Al2219/15SiCp and Al2219/15SiCp-3Gr using carbide and carbide coated drills. (b) Variation of burr height with cutting parameter for Al2219/15SiCp and Al2219/15SiCp-3Gr composite when drilling with carbide and carbide coated drills [5]

Shanta Mohapatra, et al.[6] developed a Al hybrid composite with micro Ti particles as micro Al_2O_3 or nano Al_2O_3, investigation done on micro-structural characterization and evaluated micro hardness, corrosion and wear behavior. And also compared with the basic composition for Al hybrid composites of Al+Ti+micro Al_2O_3 and Al+Ti+Nano Al_2O_3, found the better hardness, inferior to corrosion and higher wear resistance. The test results were indicated that, when the composite reinforced with Al+Ti+ Nano Al_2O_3 particles given higher hardness and better wear resistance then other reinforced particles, supported results as shown in figure 4.

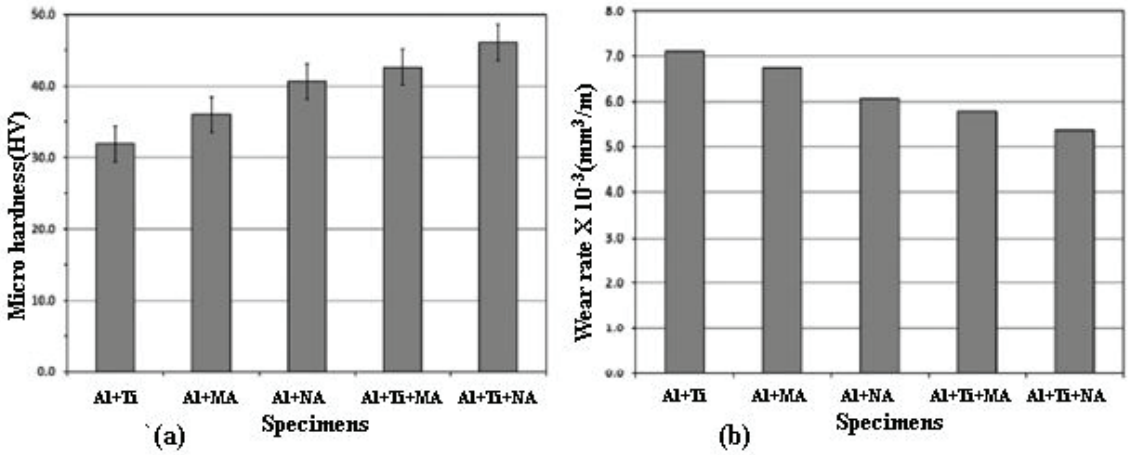

Figure 4. (a) Variation of Avg micro-hardness, (b) Variation of volumetric wear rate for all the Al based composites [6].

S Dhandapani, et al.[19]Al metal matrix reinforced with multi-wall carbon Nano tubes as well as micro-B_4C particles, they studied synthesis and characterization of the hybrid composite at various wt% of multiwall carbon tube with fixed wt%B_4C as shown in Table 1

Table 1. Typical parameters used in compaction and sintering conditions.

Sample Type	Composition	Pressing data		Sintering	Time
		N/m2	Lubricant	Temp 0C	Hrs
A	Al90 wt% + 10 wt%B4C	400	Zinc stride	420	3
B	Al89 wt% + 10 wt%B4C08 wt%+1wt% MWCNT	450	--	420	3
C	Al88 wt% + 10 wt%B4C0% +2 wt% MWCNT	500	--	420	3

The specimens prepared by uni-axial cold pressing and later green compact. Mechanical properties such as density and micro hardness were investigated, conformed that the addition in wt% of multi-wall carbon Nano tubes, bonding and mechanical properties were improved. Micro structure of hybrid studied through SEM, XRD, EDAX, AFM and TEM**.**

4.2 Stir Casting route:

Rotor and ceramic crucible reservoir used to distribute the reinforcement particles into molten Matrix materials by mechanical stirring. Figure 5 shows the schematic diagram of experimental setup contain heating furnace with resistance to melt the base metal, feeding mechanism with ceramic nano particles and mechanical stirrer connected with electrical motor to mix the pre-heated nano particles in matrix liquid

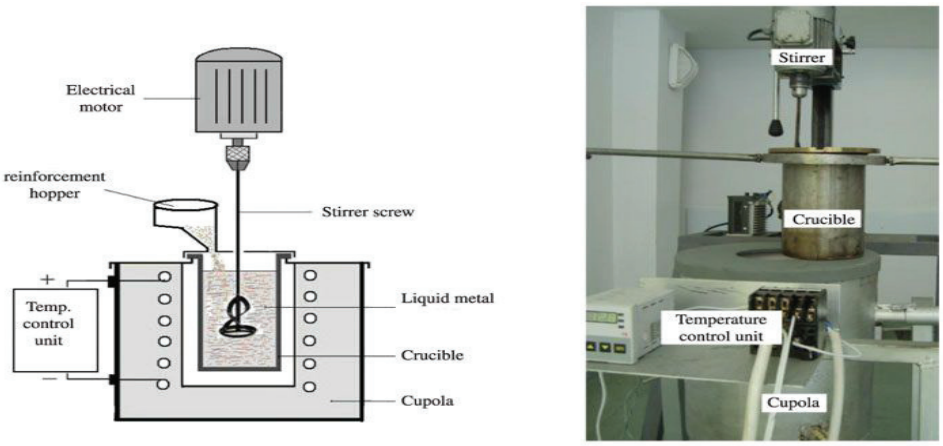

Figure 5. Schematic Diagram of Stir Casting Technique (Google image:http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-14392012000600033)

Few researchers have fabricated hybrid composites through Stir casting method[10,13,16,22-24,27,28,36,38,46,-48], conducted experiments to analyze it in various aspects, in such attempts, N Radhika et al.[14], studied hybrid composite of AlSi10Mg reinforced with alumina+Graphite and Un-reinforced alloy specimens, Investigated micro-structural analysis as well as mechanical properties such as tensile strength, double shear strength and hardness of Hybrid composite with that of Un-reinforced alloy. They found that the Hybrid MMCs were higher values than that of un-reinforced alloy. The tribological behavior of hybrid studied using Pin-On-Disc test machine, concluded that the hybrid composites had higher wear resistance compared to the un-reinforced alloy and the wear debris, and worn out surfaces analyses were done by SEM, XRDas shown in figure 6.

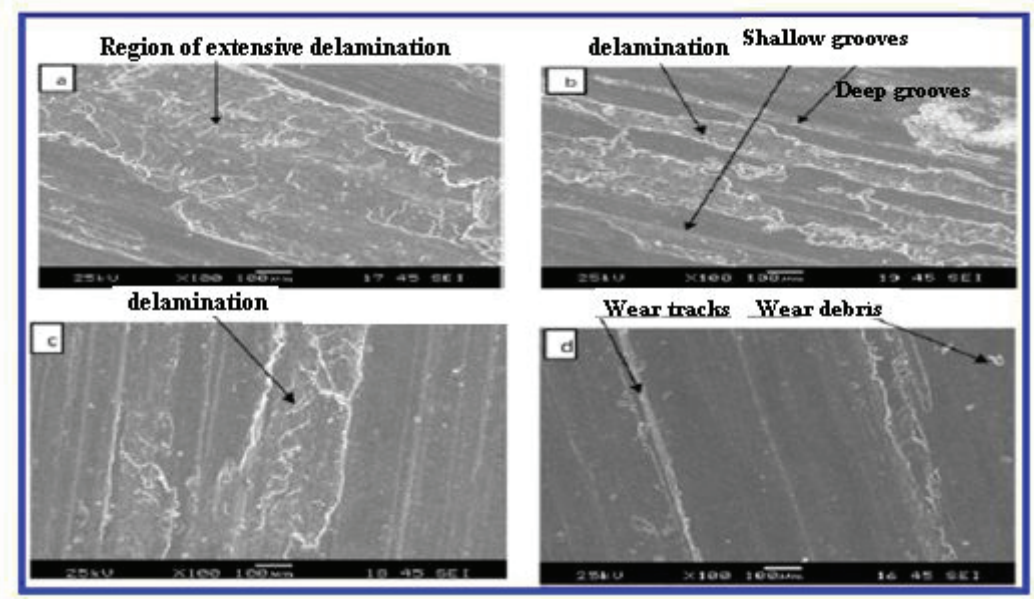

Figure 6. Scanning Electron Microscopy of worn surfaces indicating various surface morphologies: (a) Al alloy; (b) Al-3Al2O3-3Gr; (c) Al-6Al2O3-3Gr; (d) Al-9Al2O3-3Gr. [14]

S. Thirumalai Kumaran, et al.[13], deals with fabrication of AA6351+SiC+B_4C hybrid composite and prepared samples were experimented by turning test with the help of poly crystalline diamond (PCD) tool to steady the effect of B_4C, concluded that the poor surface finish observed at lower cutting speed but increases with increased depth of cut and feed rate. The quality of surface found to be low with increasing of B_4C particles, MRR increased by increasing of input parameters such as depth of cut, feed rate, cutting speed and analysis part done with Analysis of Variation(ANOVA), found the combinations for optimal output. Pradeep Sharma, et al.[16], developed the hybrid composite of AA6082+(Si3N4+Gr). Investigated mechanical properties and micro structure, analysis part were done with SEM, XRD, both micro as well as macro hardness and tensile strength of hybrid composites. Results were enhanced with the reduction in % elongation with increases in wt% of ball mill. The supported results as shown in figure 7.

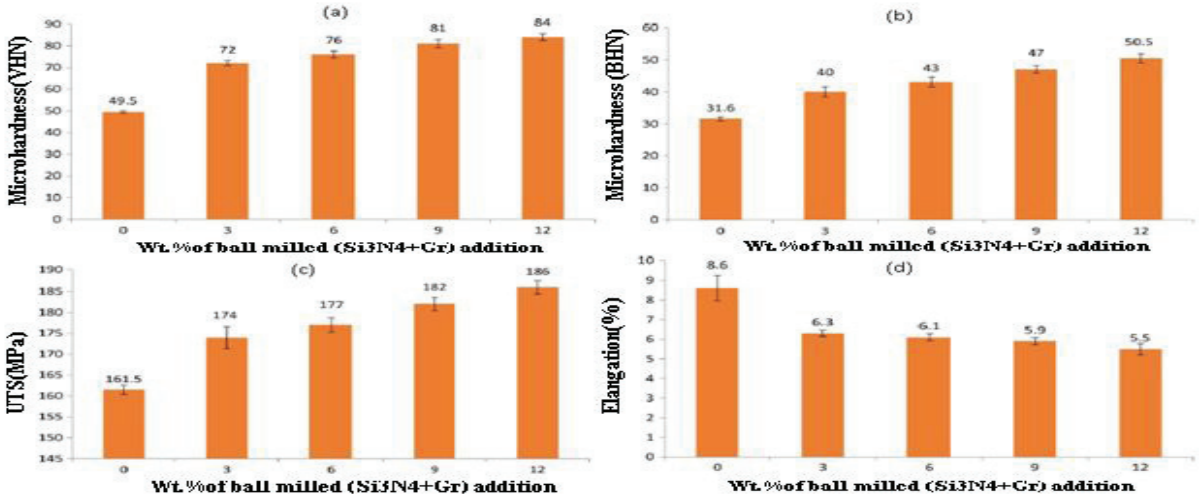

Figure 7. (a) Variation of micro-hardness(VHN), (b) variation of micro-hardness(BHN), (c) Variation of UTM, (d) Variation of percentage elongation for all with wt.% of ball milled Si3N4+Graddition[16]

A Arun Premnath[18], studied milling of hybrid (Al6061/Al_2O_3/Gr) metal matrix composites. The author observed machining parameter such as feed, depth of cut and catting speed, found the optimal machining parameters for surface roughness, tool wear and cutting force by using Response surface methodology(RSM). Analysis part is done by the analysis of variation (ANOVA) to determine the optimal parameters and desirability function approach was used for multiple response optimization.

4.3 Two step stir casting method:

It is the resent interesting development contains Matrix material heating above its melting temperature and then cool down to a certain temperature between liquid-solidus points. At this stage, preheated nano reinforcement particles are added and mixed. The slurry heated again to fully liquid state and stirred thoroughly. It was used to prepare hybrid composites by K.K. Alaneme et al[41] for (Al+bamboo leaf ash +Al2O3) hybrid composite and Al–Mg–Si alloy[41-44,45,46,47] as a base material with different nano reinforcement particles to prepare HBCs, in such connections through two-step stir casting[41-43,34]was used to enhanced various properties.
Kenneth Kanayo Alaneme et al[42], investigated the wear and corrosion behavior of Al–Mg–Si alloy material(reinforced with rice husk and SiC particles) which was fabricated through double stir casting technique. Potentio dynamic polarization measurements and open circuit corrosion potential (OCP)

were used to steady the corrosion behavior. The corrosion resistance was improved by reinforcement of SiC and Rice husk ash, SiC had great corrosion as well as wear resistance.

Kenneth Kanayo Alaneme et al[43], investigated the wear and corrosion behavior of Al–Mg–Si alloy material(reinforced with rice husk ash and Alumina particles) which was fabricated through double stir casting technique. The results indicated that the Al-Mg-Si/10wt% Al2O3 single reinforced composites were superior than Hybrid MMCs in NaCl 3.5 percentage solution. Corrosion rate increased with increasing of Wt% risk husk ash in the hybrid composites and wear rate also increases with the addition of Wt% risk husk ash.

4.4 Squeeze casting:

Squeeze casting is the combination of gravity as well as forging, uses an accurately measured quantity of molten metal which is poured into a heated mold. Pressure is applied continuously to the molten metal until it solidifies and forms a desired shape component.

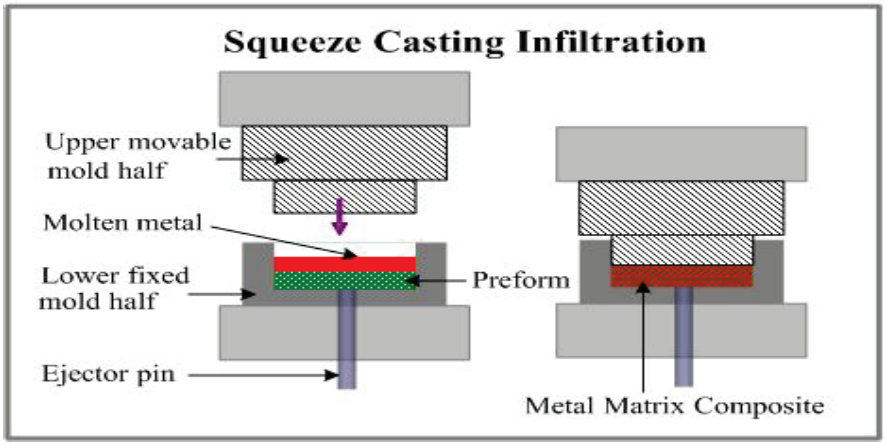

Figure 8. Schematic Diagram of Squeeze Casting Technique(Google Image: www.substech.com/dokuwiki/doku.php?id=liquid_state_fabrication_of_metal_matrix_composites)

X.X Zhang, et al[8], used squeeze casting technique to prepare SiC+ Carbon Nano Tubes/6061Al Hybrid composite, investigated the effect of heat treatment and hot extrusion and their bond strength. Experimental results were concluded that the reaction occurred in CNTs-Al at 580^0C to enhance the strength of bond, activation energy between carbon Nano tubes(CNTs) and 6061Al is found to be higher then between carbon Nano tubes and 2024Al. As well as the bond strength between carbon Nano tubes/SiC and Aluminum improved in Heat Treatment of hot extrusion at 580^0C. S.K Thakur, et al.[17], prepared Magnesium alloy metal matrix hybrid composite with the reinforcement of SiCp, carbon fiber and in-situ Mg_2Si, in order to analyze the micro structure of Hybrid composites in the cast condition, author had used optical microscope as well as SEM

Other methodologies were followed many researchers and some are as follows, K Sushanth et al.[4] prepared a hybrid composite of Banana/Glass fiber reinforced polypropylene through melt-blending technique. Studied and reported an increase in flexural, tensile and impact strengths with an increase of fiber content, absorption rate of hybrid composite decreasing due the presence of coupling agent and glass fiber. In this paper the nature of fiber matrix was tested through SEM analysis of tensile fractured specimen and thermal measurements were also carried out by Differential scanning calorimetry. S C Tjong et al and Devaraju et al used Friction stir process[9,18,19,31] to prepare the hybrid surfaces by using various nano reinforcement. Due to this process, the mechanical and tribological properties were increased. L Poovazhagan et al[45] successfully fabricated HBC(Al+SiC+B4C) by using ultrasonic cavitation based solidification process and concluded the addition of nano particle

increase in tensile strength and it obtained at 0.5 Vol% B4C and 1.0 of Sic Vol%. Reddy G et al[50] prepared hybrid composites(Cu+TiC+Gr) and successfully sintered using Microwave hybrid sintering technique for Electrical sliding contact applications. An investigation did for the effect of TiC, Graphite reinforcements on mechanical as well as physical properties of hybrid composites, found to be hybrid composites shown higher sintered density, relative density and hardness when is it compared to conventionally sintered composites.

M Rahail Parvaiz et al[11], has done the preparation and characterization of poly ether ketone (PEEK)/fly ash/mica hybrid composites having filler combinations of fly ash to mica ratios at 5:15,10:10,15:5, investigated the performance of the hybrid composites, results found that the hybrid composites of 20 wt% fly ash and mica with other combinations given that the high mechanical properties and Dielectric strength.Sudhir Kumar saw et al[12], investigated the effect of hybridization of jute fiber on the mechanical properties and water absorption property. Results were concluded that the pure coir composite had the highest water absorption and thickness swelling when it compares with another type of composites. Pure jute composite showed as the lowest thickness swelling and water absorption and highest density as compared with other composite materials.

N Selvakumar et al[14], fabricated magnesium metal matrix composite reinforced with TiC and molybdenum di-sulfide through powder metallurgy route, reported the effect of both TiC and MoS_2 on tribological properties[34], Wear test performed individually(TiC and MoS_2) reinforced composite and together reinforced hybrid with different combinations by Pin On Disc at dry sliding condition. The experimentation designed by Taguchi technique with L27 for 5 factor, 3leval system. they concluded with the results that the wear resistance of magnesium metal matrix hybrid composite was improved significantly by adding of TiC & MoS_2. Blaza Stojanovic, et al.[20] were used a full factorial method to analyze the tribological behavior of hybrid composites (A356/10SiC/1Gr and A356/10SiC/3Gr). A number of tests were conducted using a block on disc tribometer without lubricant. They studied the effect of load, sliding speed, sliding distance and wt% of Gr, concluded increases the load, sliding speed, sliding distance - increases wear rate of hybrid. And at 1wt% Gr, the specific wear rate decreases. Further increases of 3wt% Gr, causes an increase in specific wear rate. And the factorial design technique found to be a simple, systematic and efficient method for optimizing of wear test parameters.

5. Conclusion:

The major contribution of the Researchers on Aluminium, Copper, magnesium alloys to boost the mechanical and tribological properties of Hybrid composites with tremendous strength, lightweight as well as cost effective less was well received and followed. This paper presented the performance of recommended, the hybrid composites as they are better then nano composites and other current conventional composites when it is fabricated through stir casting route because a uniform and fine dispersion of nano sized ceramic particles provided good stability between reinforced particles and inter particle spacing effects to maximize the mechanical and tribological properties

References:

[1] Wu H F, WuL L, A study of tension test specimens of laminated hybrid composites. 1 Methods of approach. In: *Elsevier Science Limited*,1995.

[2] Wu H F, WuL L, A study of tension test specimens of laminated hybrid composites,Part II Size and alignment effects. In:*Journal Of Materials Science* **29** (1994) pp5847-5851

[3] Nayak D, Ray N, Sahoo R, & DebataM, Analysis of Tribological Performance of Cu Hybrid Composites Reinforced with Graphite and TiC Using Factorial Techniques. In:*Tribology Transactions, Taylor and Francis*,2014.

[4] Sushanta K. Samal , Smita Mohanty & Sanjay K. Nayak, Banana/Glass Fiber-Reinforced Polypropylene Hybrid Composites: Fabrication and Performance Evaluation, Polymer-

Plastics Technology and Engineering,*Taylor and Francis*,2009.

[5] S. Basavarajappa & G. Chandramohan & J. Paulo Davim & M. Prabu & K. Mukund & M. Ashwin & M. Prasanna Kumar, Drilling of hybrid aluminium matrix composites, *Int J Adv Manuf Technol* (2008) **35**:pp1244–1250

[6] Shanta Mohapatra[1], Anil Kumar Singh Bankoti, Ashok Kumar Mondal, Arunachalam Thirugnanam, Dry Sliding Wear and Corrosion Behavior of Al-Based Hybrid Composites Reinforced with Micro-Tip and Micro/Nano-Al2O3p, *The Indian Institute of Metals* - **IIM** 2015.

[7] Riaz Ahamed A& Asokan A & Aravindan S, EDM of hybrid Al–SiCp–B4Cp and Al–SiCp–Glassp MMCs, *Int J Adv Manuf Technol* (2009) **44**:pp520–528.

[8] Zhang X X, Wei H M, Li A B , Fu Y D& Geng L, Effect of hot extrusion and heat treatment on CNTs–Al interfacial bond strength in hybrid aluminium composites, Composite Interfaces, *Taylor and Francis*,2013.

[9] Almomani M , Hassan A M, Qasim T and Ghaithan A, Effect of process parameters on corrosion rate of friction stir welded aluminium SiC–Gr hybrid composites, *Corrosion Engineering, Science and Technology,* 2013.

[10] Radhika N and Subramanian R, Effect of reinforcement on wear behaviour of aluminium hybrid composites, *Tribology*, 2013.

[11] Rahail Parvaiz M, Mahanwar P A , Smita Mohanty & Sanjay K. Nayak, Fabrication of High Performance Fly Ash/Mica/Poly(ether-ether-ketone) Hybrid Composites, *International Journal of Polymeric Materials and Polymeric Biomaterials*, *Taylor and Francis*,2010.

[12] Sudhir Kumar Saw, Khurshid Akhtar, Narendra Yadav& Ashwini Kumar Singh, Hybrid Composites Made from Jute/Coir fibers: Water Absorption, Thickness Swelling, Density, Morphology, and Mechanical Properties, *Journal of Natural Fibers,* 2014.

[13] Thirumalai Kumaran S, Uthayakumar, Adam Slota M, Aravindan S & Jerzy Zajac, Machining behavior of AA6351–SiC–B4C hybrid composites fabricated by stir casting method, *Particulate Science and Technology, Taylor and Francis*,2015.

[14] Selvakumar N & Narayanasamy P, Optimization and effect of weight fraction of MoS2 on the tribological behavior of Mg-TiC-MoS2 hybrid composites, *Tribology Transactions, Taylor and Francis*,2015.

[15] Rajmohan T& Palanikumar K, Optimization of Machining Parameters for Surface Roughness and Burr Height in Drilling Hybrid Composites, Materials and Manufacturing Processes, *Taylor and Francis*,2011.

[16] Pardeep Sharma, Satpal Sharma & Dinesh Khanduja, Production and Characterization of AA6082- (Si3N4+Gr) Stir Cast Hybrid Composites, *Particulate Science and Technology*, *Taylor and Francis*,2016.

[17] Thakur SK, Dhindaw BK, Hort N, And Kainer KU, Some Studies on the Thermal-Expansion Behavior of C-Fiber, SiCP, and In-Situ Mg2Si-Reinforced AZ31 Mg Alloy–Based Hybrid Composites, *Metallurgical And Materials Transactions*, 2004.

[18] Arun Premnath A, Studies on Machining Parameters While Milling Particle Reinforced Hybrid (Al6061/Al2O3/Gr) MMC, *Particulate Science and Technology, Taylor and Francis,* 2015.

[19] Dhandapani S, Rajmohan T, Palanikumar K & Charan M, Synthesis and characterization of dual particle (MWCT+B4C) reinforced sintered hybrid aluminum matrix composites, *Particulate Science and Technology, Taylor and Francis*,2015.

[20] Blaža Stojanović, Miroslav Babić, Sandra Veličković & Jasmina BlagojevićTo, Tribological behavior of aluminum hybrid composites studied by application of factorial techniques, *Tribology Transactions, Taylor and Francis*,2015.

[21] Ganeshan pandi, Sarvanan Muthusamy, A review on machining and tribological behaviors of aluminium hybrid composites, *Published by Elsevier Ltd,* pp1877-7058 © 2012.

[22] Sasimurugan T and Palanikumar T, Analysis of the Machining Characteristics on Surface Roughness of a Hybrid Aluminium Metal Matrix Composite (Al6061-SiC-Al2O3), Journal

of Minerals & Materials Characterization & Engineering, Vol. 10, No.**13**, pp1213-1224, 2011.

[23] Jaswinder Singha, Amit Chauhan , Characterization of hybrid aluminum matrix composite for advance applications- a review, *J mater res techno,* 2015

[24] T. Rajmohan T, K. Palanikumar K, S. Ranganathan S, Evaluation of mechanical and wear properties ofhybrid aluminium matrix composites,*Trans. Nonferrous Met. Soc. China* **23** pp2509−2517,2013

[25] Krishnamurthy L and Sridhara BK, Comparative study on the machinability aspects of aluminum- silicon carbide and aluminum-graphite-silicon carbide hybrid, *Int. J. Machining and Machinability of Materials,* Vol. 10, Nos. **1/2**, 2011

[26] Akhlaghi L and Mahdavi S, Effect Of The Sic Content On The Tribological Properties Of Hybrid Al/Gr/SiC Composites Processed By In Situ Powder Metallurgy (Ipm) Method, *Advanced Materials Research* Vols. **264-265** (2011) pp1878-1886

[27] RajmohanT, PalanikumarK, Ranganathan S,Evaluation of mechanical andwear properties of hybrid aluminium matrix composites, *Trans. Nonferrous Met. Soc. China*23(2013) pp2509−2517.

[28] Arun Kumar M. Band Swamy RS Evaluation Of Mechanical Properties OfAl6061, Flyash And e-Glass Fiber Reinforced Hybrid Metal MatrixComposites .*ARPN Journal of Engineering and Applied Sciences*, 2011

[29] Harish K.Garg, Ketan Verma, Alakesh Manna, Rajesh Kumar , Hybrid metal matrixcomposites and further improvement in their machinability– a review,*International Journal of Latest Research in Science and Technology*, Vol.1,Issue 1 :pp**36**-44,May-June(2012)

[30] Zoltán Károly , Csaba Balázsi, Katalin Balázsi, Attila Petrik, János Lábár, and Ayaj Dhar, Hybridaluminium matrix composites prepared by spark plasmasintering (SPS), 2014

[31] Devaraju A, Kumar A, Kotiveerachari B, Influence of addition of Grp/Al2O3p with SiCp on wear properties of aluminum alloy 6061-T6 hybrid composites via friction stir processing, *Trans. Nonferrous Met. Soc.* China **23**(2013) pp1275−1280,

[32] Devaraju A, Kumar A, Kotiveerachari B, Influence of rotational speed and reinforcements on wear and mechanical properties of aluminum hybrid composites via friction stir processing, *Materials and Design* 45 (2013) pp576–585.

[33] Ravindran P,Manisekar K Vinoth Kumar S, Rathika P, Investigation of microstructure and mechanical properties ofaluminum hybrid nano-composites with the additions ofsolid lubricant, Materials and Design **51** (2013) pp448–456

[34] Dora Siva Prasada, Chintada Shobab, Nallu Ramanaiahc,Investigations on mechanical properties of aluminum hybrid composites, *Journal of mater res technol*. 2014;**3(1):**pp79–85

[35] Alaneme KK, Ademilua BO, Bodunrin MO, Mechanicalproperties and corrosion behaviour of aluminium hybridcomposites reinforced with silicon carbide and bamboo leafash, *Tribology in Industry*, Vol. 35, No. **1** (2013) pp25-35.

[36] Thirumalai T, Subramanian R, Kumaran S, Dharmalingam S, Ramakrishnan SS, production and characterization of hybrid aluminium matrix composite reinforced with B4C and Gr, *Journal of scientific and Industrial research*,2014.

[37] Rajmohan T, Palanikumar K , Arumugam S, synthesis andcharacterization of sintered hybrid aluminium matrixcomposites reinforced with nanocopper oxide particles andmicrosilicon carbide particles, *Composites*: Part B **59** (2014) pp43–49

[38] Suresha S, Sridhara BK, Wear characteristics of hybrid aluminium matrix composites reinforced with graphite and silicon carbide particulate, *Composites Science and Technology* 70 (2010) 1652–1659

[39] Mahmoud, Essam R.I, Makoto Takahashi, Toshiya Shibayanagi, Kenji Ikeuchi, Wear characteristics of surface-hybrid-MMCs layer fabricated on aluminum plate by friction stir processing, *Wear* **268** (2010) pp1111–1121.

[40] Tjong SC, Lau KC, and Wu SQ, Wear of Al-based hybridcomposites containing BN and SiC particulates, *Metallurgical And Materials Transactions*, a Volume 30a, September 1999—2551

[41] Alaneme K K, Olubambi PA, Afolabi AS, Bodurin MO, Corrosion and tribological studies of bamboo leaf ash andalumina reinforced Al-Mg-Si alloy matrix hybrid compositesin chloride medium, *Int. J. Electrochem. Sci*., **9** (2014) 5663 - 5674.

[42] Kenneth Kanayo Alaneme, Tolulope Moyosore Adewale, Peter Apata Olubambi, Corrosion and wear behavior of Al-Mg-Si alloy matrix hybrid composites reinforced with rice husk ash and silicon carbide.*Journal of mater res technol* . 2 0 1 4;**3(1)**:pp9–16

[43] Kenneth Kanayo Alaneme, Peter Apata Olubambi, Corrosion and wear behaviour of rice husk ash—Alumina reinforced Al–Mg–Si alloy matrix hybrid composites, *Journal of mater res technol*. 2013;**2(2)**:pp188–194.

[44] Pech-Canul M A, Pech-Canul MI, Escalera-Lozano R , Gutiérrez C A, Corrosion characteristics of hybrid Al/SiCp/MgAl2O4composites fabricated with fly ash and recycled aluminum, *Materials Characterization***58** (2007) pp953–960.

[45] PoovazhaganL, Kalaichelvan.K, Rajadurai.Aand Senthilvelan.V, Fabrication characteristics and mechanical behaviour of rice husk ash – Alumina reinforced Al-Mg-Si alloy matrix hybrid composites,*Procedia Engineering* **64** (2013) pp681 – 689.

[46] Oluwagbenga Babajide Fatile1, Joshua Ifedayo Akinruli1 and Anthony Akpofure Amori2 , Microstructure and Mechanical Behaviour of Stir-Cast Al-Mg-Sl Alloy Matrix Hybrid Composite Reinforced with Corn Cob Ash and Silicon Carbide, *International Journal of Engineering and Technology Innovation*,2014

[47] Venkat Prasat S, Subramanian R, Tribological properties ofAlSi10Mg-(fly ash)-graphite hybrid metal matrix composites,Industrial Lubrication and Tribology **65/6** (2013) pp399–408.

[48] Prakash C.H.1 and Pruthviraj R.D.2, Microstructural Studies of Cast Zinc - Aluminum-Sic-Graphite Hybrid Composites, Research Journal of Chemical Sciences, Vol. 1(6), pp**88**-90, Sept. (2011)

[49] Mitrović S, Babic M, , Stojanović B, Miloradović N, Pantić M,Džunić D, Tribological Potential of Hybrid Composites Based on Zinc and Aluminium Alloys Reinforced with SiC and Graphite Particles,*Tribology in Industry,* Vol. 34, No. **4** (2012) pp177-185.

[50] Reddy G. Chandrakanth & Rajkumar K&Sivanandam AravindanFabrication of copper–TiC–graphite hybrid metal matrix composites through microwave processing, *International Journal of Adv Manuf Technol* (2010) **48**:pp645–653

[51] Zhan Y Z, Shi X B and Xie H F, Microstructural investigation on antifriction characteristics of self-lubricating copper hybrid composite, *Materials Science and Technology,* 2006 VOL **22** NO 3.

[52] Wong WL E, Karthik S, Gupta M, Development of hybrid MgAl2O3 composites with improved properties using microwave assisted rapid sintering route, *Journal Of Materials Science* **40** (2005) pp3395 – 3402.

[53] A. Yamada, H. Sasabe, Y. Osada and Y. Shiroda, I. Concepts of Hybrid Materials, Hybrid Materials –Concept and Case Studies, *ASM International*, OH, USA, 1989.

[54] A. Makisima, "Possibility of Hybrids Materials", *Ceramic Japan, **39***,(2004) 90-91.

[55] Y.L. XiT, D.L. Chai, W.X. Zhang, J.E. Zhou, Ti–6Al–4V particle reinforced magnesium matrix composite by powder metallurgy, *Materials Letters **59*** (2005) 1831 – 1835

[56] J. I. Song, K.S. Han, Mechanical Properties and Solid Lubricant Wear Behavior of Al/Al2O3/C Hybrid Metal Matrix Composites Fabricated by Squeeze Casting Method, *Journal of Composite Materials February* 1997 **31**: 316-344.

[57] X.Zhang, M.l.Tan, Selection of particulate reinforcement in P/M metal matrix composites, *Journal of Materials Processing Technology***63** (1997) 913-917

[58] Riccardo Casati and Maurizio Vedani, Metal Matrix Composites Reinforced by Nano-Particles—A Review, *Metals* 2014, **4**, 65-83