RESEARCH PAPER | Engineering | Volume : 4 | Issue : 3 | Mar 2014 | ISSN - 2249-555X

Study on Fabrication processes and Machinability of Metal Matrix composites – A review on Advanced Applications

KEYWORDS: Metal matrix composites, Aluminium oxide; Aluminium carbide,Intermetallics ,Self-lubricating composites, Silver molybdate, High temperature ,Thermal spray, Silicon carbide, Magnesium alloy Friction , hard facing, WC–Ni based metal matrix composite, Analytical modeling, Mechanical testing, Stir casting, Thixoforging process, Metal injection molding , Wet ability, diffusion bonding, Laser processing

S.Prabagaran	G.Chandramohan	P.Shanmughasundaram
Department of Mechanical Engineering, Karpagam University, Coimbatore-641021	Director – Academic, Sri Krishna College of Technology, Coimbatore-641042	Department of Mechanical Engineering, Karpagam College of Engineering, Coimbatore – 641032

ABSTRACT *Characterization of Metal matrix composites like fabrication processes, machinability were explored in this study. Fabrication methods were explored for various composites which were giving positive characterization in this article. Few processes were discussed where we see good surface finish, dimensional accuracy, elimination of porosity and shrinkage, high strength to weight ratio, improved wear resistance, higher corrosion resistance, higher hardness, resistance to high temperature, improved fatigue , better creep strength and ductility.In specific fabricating metal matrix composites by Metal Injection Mould-ing which is a near net-shape manufacturing technology that is capable of mass production of complex parts cost-effectively. The unique feature of this process make it an attractive route for the fabrication of metal matrix composite materials.Centrifugal casting process capable of achieving high pressures for fabrication of metal matrix composites was dem-onstrated resulting finer particle distribution, micro segregation in the matrix, and the soundness in quality. Spark plasma sintered composites from the mixtures of Si and Al phases was demonstrated to result Si grains distributed in the Al matrix homogenously. At lower stirring speed and lower stirring time particle clustering of SiC particles with high Al.alloy was more alongwith uniform hardness. At higher stirring speed and stirring time of same resulted better distribution of particles at un-uniform hardness.*

Introduction

Composites are one of the most widely used materials because of their adaptability to different situations and the relative ease of combination with other materials to serve specific purposes and exhibit desirable properties. Area of applications of composites are very wide. Amongst, most predominant applications area are Automotive parts, Civil Aircraft , Military Aircraft, General aviation, Buildings Construction, Bridges construction , Roads construction, Energy Production and Distribution, Timber replacement , Jute Coir Composites, Bamboo based Composites, Rebuilding and Rehabilitation, Tourism House boats, Composite Pressure Vessels , Under Water Vehicles , Deep Ocean Equipments , High pressure accumulator bottles , Medical , Railway locomotives accessories etc. Many applications are still depending on properties of these composites. Few are well established without any technical issue. Few composites are still under research and development to reach maximum utilization on application front. They are Wear resistant, Mechanical properties , Microstructure , Machinability, Corrosion properties , Thermal properties etc. Since the applications are astounding it becomes necessary to go through different composites in detail which are rich in above properties so that we get best mileage out of applications in reality. Keeping this in mind Authors made an extensive survey of relevant articles pertainint to fabrication and machinability of metal matrix composites and made a consolidation of review in this article. Despite the superior mechanical and thermal properties of particulate metal matrix composites,their poor machinability is the main deterrent to their substitution of metal parts. Machining is a material removal process and therefore is important for the final fabrication stage prior to application. Consequently the development of effective machining methods,leading to a reduction in the overall cost of components,is one of the major challenges yet to be solved

CHARACTERISATION BY FABRICATION PROCESSES

Articles related to Composites fabrication processes are studied and the gist of results and discussions are consolidated herewith. This gives a brief detail about the salient features of different manufacturing processes that are relevant to different applications.

Rajan et al.,[1] made an investigation on the effect of three different stir casting routes on the structure and properties of fine fly ash particles reinforced with Al–7Si–0.35Mg alloy composite was evaluated. Among liquid metal stir casting, compocasting (semi solid processing), modified compocasting followed by squeeze casting routes evaluated, the latter has resulted in a well-dispersed and relatively agglomerate and porosity free fly ash particle dispersed composites. Interfacial reactions between the fly ash particle and the matrix leading to the formation of $MgAl_2O_4$ and iron intermetallics are more in liquid metal stir cast composites than in compocast composites**. Hezhou et al.,[2]** discussed the research and development in fabricating metal matrix composites by Metal Injection Moulding which is a near net-shape manufacturing technology. In this paper, the status is reviewed, with a major focus on material systems, fabrication methods, resulting material properties and microstructures. Also, limitations and needs of the technique in composite fabrication were presented by authors in paper.

Vijayaram et al., [3] worked with a special casting technique that combines the advantages of traditional high pressure die casting, gravity permanent mold die casting and common forging technology. Outcome of work was good surface finish,dimensional accuracy,elimination of porosity and shrinkage, high strength to weight ratio, improved wear resistance, higher corrosion resistance, higher hardness, resistance to high temperature, improved fatigue better creep strength and ductility. This paper reviews about the principles of squeeze casting technology, which can be applied to process discontinuous fiber reinforced metal matrix composite castings

Volume : 4 | Issue : 3 | Mar 2014 | ISSN - 2249-555X

Emamy et al.,[4] investigated and arrived a technique in an aluminum based metal matrix composite in order to reveal the mechanism of formation of TiB2 particles by mixing molten master alloys.It was proposed that the formation of TiB2 particles occurred via diffusion of Boron atoms through TiAl3 particles interface, thereby reacting to form fine TiB2 particles. Studies in this article indicate that primary TiB2 particles on the surface of TiAl3 are appreciably free and movable , TiB2 particles produced during growth with the primary ones formed agglomeration rings. A model was schematically developed to explain the formation of TiB2.**Murato˘glu et al.,[5]** in an article discussed extensively on Joining characteristic of SiC particulate reinforced aluminum metal matrix composites (MMCs) with pure aluminum by diffusion bonding process. The joining quality of the Al/SiCp MMC was studied to determine the influences of SiCp particulates with homogenization and age hardening on bonding properties.

Wannasin et al.,[6] developed a new centrifugal casting process capable of achieving high pressures for fabrication of metal matrix composites. In this process, higher pressures were obtained by controlling the metal level above the cavity in the rotating long runner and constant throughout the infiltration process. When the resulting structure of the infiltrated composites were studied it came to a composites fabrication process having finer particle distribution, micro segregation in the matrix, and the soundness in quality.**Ravi et al.,[7]** investigated stir casting technique through a water model to find the influence of the mixing parameters on the synthesis of Al–SiCp reinforced metal matrix composites. The variations observed in natural graphite concentration in water during mixing are in compliance with the earlier modeling and limited experimental studies reported on the real molten aluminum–SiC system.

Yu et al.,[8] in this paper demonstrated Spark Plasma Sintering which are having microelectronic applications. In this investigation they found densification behavior, microstructure, coefficient of thermal expansion and thermal conductivity of the composites were successful. Also they found the composites were the mixtures of Si and Al phases without any interaction, and Si grains distributed in the Al matrix homogenously. The average Coefficient of Thermal Expansion and Thermal Conductivity of the Sip/Al composite indicating better performances of the spark plasma sintered composites.

Sozhamannan et al.,[9] discussed in this article that Conventional stir casting process had given discontinuous particle reinforced metal matrix composites, Insufficient wetting of particle by liquid metal and non homogenous dispersion of the ceramic particles. In this study, aluminium metal matrix composites were fabricated by different processing temperatures with different holding time gave good mechanical properties. **Wahab et al.,[10]** describe in this article the preparation and characterization of aluminum metal matrix composites reinforced with aluminum nitride. Morphology of the composite and particle distribution were investigated. The reinforcing particles were clearly present at the edges and around grains of silicon primary, silicon needles and inter-metallic compound of $FeMg_3Si_6Al_8$ The result was increased hardness which indicated that the Aluminium nitride particles effect.

Hezhou Yea et al.,[11]demonstrated in their article that MIM processs provides a promising way to fabricate MMC materials and components. It is particularly cost-effective for the fabrication of small, complex parts due to its shaping capabilities.

CHARACTERISATION BY MACHINABILITY

Articles related to machinability of metal matrix composites are studied and their results of experiments were consolidated and presented herewith. This gives resonably a deep insight about the technical issues that are to be addressed yet like poor machinability, surface finish, tool flank wear and unfavourable continuous chips formation etc. and gave a st of solutions to reduce such issues by the way of incorporating suitable reinforcements for such metal matrix composites.

Gu l Tosun et al., [12] narrated in their article that Automotive, aircraft and train companies need to replace steel and cast iron in mechanical components with lighter high strength alloys like Al metal matrix composites (MMC). In this study,the influence of the type of drills,point angles of drills and ageing on the drilling performance of 2124 aluminum alloy reinforced with 17% SiC particulates was investigated experimentally. **Pramanik et al., [13]** stated in this paper that the matrix deformation and tool–particle interactions during machining using the finite element method. Based on the geometrical orientations, the interaction between tool and particle reinforcements was categorized into three scenarios: particles along, above and below the cutting path. The development of stress and strain fields in the MMC was analyzed and physical phenomena such as tool wear, particle debonding, displacements and inhomogeneous deformation of matrix material were explored. **Kannan et al.,[14]** investigated and presented an analytical tool flank wear rate model that has been developed for orthogonal cutting processes. In this approach, the wear volume loss is formulated based on the process parameters and reinforcement properties. Then, the flank wear rate is developed by considering the tool geometry in orthogonal metal cutting. The developed model was validated with orthogonal cutting tests conducted on 6061 aluminum MMC reinforced with Al O particulates under similar cutting conditions. **Mariam et al.,[15]** presented a 3D thermo-mechanical finite element model of the machined composite workpiece. The model is used to predict the effect of the different cutting parameters on the workpiece subsurface damage produced due to machining. The model predicts high localized stresses in the matrix material around the SiC reinforcement particles, leading to matrix cracking. The model results are in good agreement with the scanning electron microscope observations.

Bejjani et al., [16] stated that although ceramic particles in Titanium Metal Matrix Composites (TiMMCs) improve its wear resistance properties, they also cause high abrasive tool wear. In an attempt to enhance tool life and productivity, Laser Assisted Machining (LAM) of TiMMC was performed under different cutting conditions, an aspect that has never been investigated before. **Mohamed et al.,[17]** evaluated the machinability of the alloys was tested based on cutting force, tool wear, surface roughness, and chip type. Increasing the silicon content from 1% to 4%, results in increasing the tool wear by 140%, machined surface roughness by 25%, while the chip type changed from continuous to discontinuous type, and the cutting force was reduced by 50%. **Kannana et al.,[18],** Cutting of metal matrix composites (MMCs) has been considerably difficult due to the extremely abrasive nature of the reinforcements that causes rapid tool wear and high machining cost. An investigationwas carried out to clearly understand the role played by the ductile matrix on the machining performance based on the estimation of line defects generated as a result of cutting. The microstructural studies were conducted using transmission electron microscopy (TEM) on the machined surface to reveal the deformation pattern of the work hardening matrix and its correlation with the forces generated during turning MMCs.

Zhu et al., [19] developed a plane-strain thermo-elasto-plastic finite element model that had been used to simulate orthogonal machining of alumina/aluminium 6061 metal matrix composite using a tungsten carbide tool. Simulations were carried out employing temperature dependent material physical properties. The interface failure mode between the aluminium matrix and alumina particles was incorporated in that model. **G€ul Tosun et al.,[20]** stated that aluminum–matrix composites are widely used for their favorable specific strength/stiffness and corrosion resistance properties. As a consequence of the widening range of applications

Volume : 4 | Issue : 3 | Mar 2014 | ISSN - 2249-555X

of MMCs,which are extremely difficult to machine (turning, milling, drilling, threading) due to their extreme abrasive properties. Dry drilling tests, at different spindle-speed,feed rates, drills, point angles of drill and heat treatment, were conducted in order to investigate the effect of the various cutting parameters on the surface quality and the extent of the deformation of drilled surface due to drilling. For this reason, the surface roughness of the workpiece material was investigated after drilling operations.Drilling tests were carried out using high-speed steel (HSS), TiN coated HSS and solid carbide drills. **Pedersen et al.,[21]** made an investigation whereTiCN/TiN coated carbide cutting tools were used to study the finish machining characteristics of a silicon carbide particle reinforced magnesium metal matrix composite (SiCp/Mg MMC). A fully replicated two-level 24 full factorial with centerpoints was conducted while facing the MMC with process variables including feed, cutting speed, depth of cut and side cutting edge angle; and response variables of cutting forces, chip formation, surface roughness and tool wear.

Paulo Davim [22] presented an experimental machinability study of the metal–matrix composites (MMCs) A356/SiC/20p with brazed polycrystalline diamond (PCD) tools or chemical vapour deposition (CVD) diamond coated tools.The experimental procedure consisted of turning operations, during which cutting force, cutting tools flank wear and surface roughness obtained in composite workpiece were measured.

Davima et al.,[23] presented an experimental physical model on the cutting process for MMCs (aluminium alloy reinforced with 20% of particulate silicon carbide-SiC). The turning experiments were carried out on MMCs extruded workpieces using polycrystalline diamond (PCD) cutting tools. The objective of this study is to evaluate the chip compression ratio (Rc), chip deformation (ε), friction angle (ρ), shear angle (ϕ), normal stress (σ) and shear stress (τ), under prefixed cutting parameters (cutting velocity and feed rate). The experimental physical model was compared with the Merchant equation. **Shibendu Shekhar Roy[24]** made an attempt to design an expert system using two soft computing tools, namely fuzzy logic and genetic algorithm, so that the surface finish in ultra-precision diamond turning of metal matrix composite can be modeled for set of given cutting parameters, namely spindle speed, feed rate and depth of cut. Once trained, the GA-trained fuzzy expert system (GAFES) will be able to predict surface finish in ultra-precision diamond turning of Al6061/SiCp metal matrix composite before conducting actual experiment. The predicted surface finish values obtained from GAFES were compared with the experimental data. **Li et al.,[25]** carriedout an investigation into the mechanism of the tool wear in cutting of MMCs and found that during cutting of an MMC, the tool cutting edge will impact on the reinforcement particles. The impacted particles will then either be dislodged from the matrix, doing no harm to the tool, or be embedded into the matrix, ploughing on the tool flank and causing excessive tool flank wear. Experimental tests for cutting of SiC–aluminum MMC using coated tungsten carbide tools with and without the aid of the pressured air jet were conducted.

CONCLUSIONS

Al. matrix with Al_4C_3 reinforcement under powder metallurgical composites upto a critical temperature increases wear resistance, Hardness compression strength. Best Tribological properties are achieved from Ni based composites with Silver and Molybdenum disulphide under powder metallurgy technique. By depositing Aluminium coatings reinforced with silicon carbide particles on Mg–Zn substrates fabricated under High Velocity Oxygen-Fuel (HVOF) is very effective for enhancing wear resistance. Coefficient of friction and rate of wear can be accurately envisaged by Back Probagation Neural Network model in carbon fibre reinforced Poly(Ether)–Ether–Ketone advanced composite Wear rate of high alloy hardfacing deposit (SHS9290) with Alumina grit is higher than that inTungsten carbide–Ni based metal matrix composite (MMC). Aluminium matrix reinforced with titanium carbide composites fabricated by Stir casting method in an argon atmosphere resulting enhanced specific strength and wear resistance. Al6061–Al_2O_3 nano composites produced by milling and hot consolidation showed a maximum hardness and optimum wear rate. Al6061 composites reinforced with mixtures of SiC and Al_2O_3 particles fabricated by stir casting method resulting increase in wear with the increasing load and sliding distance. In cylinder liner part of Metal Matrix Composites fabricated under Thixoforming process, .the Mechanical properties were found to be better than that of commercial composites cylinder linear. Fabrication of aluminum metal matrix composites reinforced with tungsten carbide (WC) particles through warm accumulative roll bonding process confirmed to have excellent WC particle distribution in the Al matrices and enhanced properties of Tensile, hardness, and wear. Aluminium–magnesium–silicon alloy reinforced with Al_2O_3-based polycrystalline ceramic microspheres composites fabricated by powder metallurgy gave longer fatigue lives than the matrix alloy.

Fabricating metal matrix composites by Metal Injection Moulding which is a near net-shape manufacturing technology which has got major focus on material systems, fabrication methods, resulting material properties and microstructures. Discontinuous fiber reinforced metal matrix composite castings fabricated by squeeze casting technology resulting good surface finish, dimensional accuracy, elimination of porosity and shrinkage, high strength to weight ratio, improved wear resistance, higher corrosion resistance, higher hardness, resistance to high temperature, improved fatigue , better creep strength and ductility. A new centrifugal casting process capable of achieving high pressures for fabrication of metal matrix composites was demonstrated resulting finer particle distribution, micro segregation in the matrix, and the soundness in quality. A new process of Spark plasma sintered composites from the mixtures of Si and Al phases without any interaction was demonstrated which are having microelectronic applications resulting Si grains distributed in the Al matrix homogenously. Microstructure and mechanical properties of a three layered material B_4C/Al, B_4C/TiB_2 and B_4C composites using a two-step method for both hot pressing and aluminum infiltration in vacuum show improved fracture toughness than that of B_4C material and higher comprehensive hardness than that of B_4C/Al material. The experimental results [12] of drilling under different settings of spindle-speed and feed rate and point angles of drill indicated that,the effect of point angles on the sub-surface damage caused by the drilling operation was changed with the type of drills. It was found [13] that tool–particle interaction and stress/strain distributions in the particles/matrix are responsible for particle debonding, surface damage and tool wear during machining of MMC. Analysis of the results [16] showed that LAM can significantly increase tool life by up to 180%. The phenomenon of improved tool life at higher speeds and under LAM conditions were explained through the analysis of the chip morphology and micro-structure. This investigation [18] provided valuable information on the deformation behaviour of particulate reinforced composites that can improve the performance and accuracy of machining MMCs. The results [22] showed that PCD tools are important in cutting this composite type of reduced machinability. The predicted surface finish values obtained from GAFES were compared with the experimental data [24]. The comparison indicates that the proposed system can produce efficient knowledge base of fuzzy expert system for predicting the surface finish in diamond turning.

ACKNOWLEDGEMENTS

Authors are grateful to the management of Karpagam University, Coimbatore for providing the facilities and consistent support to carry out this review work successfully.

Volume : 4 | Issue : 3 | Mar 2014 | ISSN - 2249-555X

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