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Machining of Hybrid Metal Matrix Composites and its Further Improvement-A Review

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Abstract- In the present study based on the literature review, the machining of hybrid aluminium metal matrix composite (Al/SiC/B$_4$C) is discussed. These hybrid MMCs can easily be machined by CNC milling and a good surface quality can be obtained by controlling the machining parameters. These hybrid metal matrix composites (hybrid MMCS) are finding increased applications because of improved mechanical and tribological properties than the single reinforced composites. These materials are developed for engine blocks, bearing for steering system, propeller vanes, drive shafts in aircraft. The machining of hybrid MMCs and their improvements by use of CNC milling are discussed.

Keyword – Metal matrix composites (MMCs), Ceramics particulates, Hybrid metal matrix composites (HMMCs), Computer numerical control (CNC) milling machine.

I. INTRODUCTION

Composite materials are materials made from two or more constituent materials with significantly different physical and chemical properties. Composites materials offer high strength to weight ratio, good fatigue resistance and corrosion resistance which make them highly competitive against conventional materials. These composites materials are widely used in construction, aerospace and transportation industries as well as military application. In today's engineering world many classes of composites materials have emerged, including polymers matrix composites, metal matrix composites, ceramic matrix composites. Composites materials in general exhibit inhomogeneity, anisotropy and non- ductile behavior. In many developed countries and developing countries there exists continued interest in metal matrix composites (MMCs). Researchers tried numerous combinations of matrices and reinforcement since work on MMCs began in 1950s. This made to developments for aerospace applications. In 1960s ceramic as reinforcement are used for high temperature application in aircraft engine.

In the last 20 years metal matrix evolved from laboratories to class of materials with numerous applications and commercial markets. So as to improve further the properties of MMCs more than two materials were added in the matrix such that to give birth to hybrid metal matrix composites (HMMCs). Since long back metal matrix composites (MMCs) were introduced in the aeronautics industries and later on reached to automobile industry.

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However, MMCs are not widely used in these industries due to their poor performance in machinability. Metal matrix composite is a composite material with at least two constituent parts, one being a metal, and other being a different material such as a ceramic or organic compound. MMCs with discontinuous reinforcements are usually less expensive to produce than continuous fiber reinforced MMCs, although this benefit is normally offset by their inferior mechanical properties. Consequently, continuous fiber reinforced MMCs are generally accepted as offering the ultimate in terms of mechanical properties and commercial potential. The major advantages of aluminium metal matrix composites (AMCs) over traditional Materials e.g. iron, steel and other Non-ferrous materials are as follows:

- Low density
- High strength to weight ratio
- Improved wear resistance
- High specific stiffness
- Improved damping capabilities
- Tailor able thermal expansion co-efficient
- Good corrosion resistance etc.

The Limitation of composites are : Mechanical characterization of a composite structure is more complex than the metallic structure, the fabrication cost of composites is high, rework and repairing are difficult, they do not necessarily give higher combination of strength and fracture toughness as compared to metals. The common applications of composites are extending day by day. Some of the fields of application are: Automotive: Engine block, frames, automotive racing brakes, leaf springs for heavy trucks and trailers, bumpers, body panels and doors. Space: Remote manipulator arm, high gain antenna, antenna ribs and struts etc. Marine: propeller vanes, fans and blowers, gear case, condenser shells. Aircraft: drive shaft, bearings, panels and floorings of airplanes etc. Chemical industries: Composite vessels for liquid natural gas for alternative fuel vehicle, storage tanks, duct etc. The hybrid metal matrix composites are unique material fabricated by reinforcements of at least two types of ceramic particles in a tough metal matrix. The usage of aluminium- carbide composites have been increased in the industries of automotive, aircraft, locomotive companies and advanced arm systems. Due to the reinforcement of ceramic materials, the machining of these metal matrix composites become more difficult than those of conventional materials. The non-homogenous and anisotropic nature combined with abrasive reinforcement render their machining difficult. The tool wear rate is very high and the work piece may get damaged due to the plucking effect of the tool on the ceramic particles.

These factor lead to uneconomical machining resulting poor surface quality. The Machinability of a material may be evaluated by assessing any one of the machining parameter like surface roughness, cutting force, power consumption and tool life.

II. MATRIX AND REINFORCEMENT SELECTION

A. Aluminium Matrix Selection

The reasons for aluminium being a success over magnesium and titanium is said to be mainly due to the design flexibility, good corrosion resistance, low density, good wettability and strong bonding at the interface. However, the density of magnesium is 35% lower than that of the aluminium, strength/density values makes aluminum to competitive.

B. Aluminium Alloy Selection

The aluminium alloys are represented by 1XXX, 2XXX, 3XXX up to 8XXX. The first digit gives basic information about the principal alloying elements. The second digit gives the information about the alloy modification. If the second digit is zero, it indicates the original alloy: digits 1 through 9, which are assigned consecutively, indicate alloy modifications. The last two digits have no special significance, serving only to identify the different alloys in the group. The 1xxx, 3xxx and 5xxx series are so called as non-heat-treatable alloys which gain their strength by alloying and work hardening. The 8xxx series designations are for miscellaneous types of alloys (i.e. Fe alloys) which cannot be grouped in the other families. The 2xxx, 6xxx and 7xxx series are heat-treatable alloys, which gain their strength by alloying but make use of precipitation hardening as the main mechanism. Among several series of aluminium alloys, heat treatable Al6xxx and Al7xxx are much explored. Al6xxx alloy is highly corrosion resistant, extricable in nature and exhibits moderate strength. It finds vast applications in the fields of construction, marine, automotive, aerospace and other fields. Table 1 shows the chemical composition Wt % of Al-6061 matrix material.

Table 1 Chemical Composition of Al 6061

Element	Mg	Si	Fe	Cu	Mn	Zn	Ti	Cr	Al	Others
% Wt	0.8 – 1.2	0.4 - 0.8	0.7 Max	0.15 – 0.4	0.15 Max	0.25 Max	0.15 Max	0.04-.35	95.8 – 8.6	0.15 Max

C. Reinforcement

As for the reinforcement, the materials used are typically ceramics since they provide a very desirable combination of stiffness, strength and relatively low density. The reinforcement materials include SiC, Al_2O_3, B_4C, TiC, graphite and a number of other ceramics. Many ceramics particles of interest are thermodynamically unstable when they are in contact with pure metals, and will react to form reaction compounds at the interface between the particles and the surrounding matrix.

D. Silicon Carbide (SiC)

Silicon carbide can be used as reinforcement in the form of particulates, fibers to improve the properties of the composite. When embedded in metal matrix composites SiC certainly improves the overall strength of the composite along with corrosion and wear resistance. Aluminium MMCs reinforced with SiC particles have up to 20% improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than un-reinforced matrix alloy. Due to high hardness SiC has a number of applications such as in cutting tools, jewellery, automobile parts, structural materials etc. for these reasons SiC-particulate-reinforced aluminium composites have found many applications such as brake discs, bicycle frames, aerospace and automotive industry.

E. Boron Carbide (B4C)

Boron carbide is the third hardest material after diamond and cubic boron nitride, which possesses low density, high degree of chemical inertness, high temperature stability, excellent thermoelectric properties, is an attractive strengthening agent for aluminium based composites. One of the solutions is going for boron carbide-reinforced metal matrix composites that are stronger, stiffer, fracture resistant, lighter weight, and harder, possess higher fatigue strength and exhibit significant improvements over other materials. The lower density, higher elastic modulus, higher refractoriness and higher hardness of B_4C than SiC and Al_2O3 make it better reinforcement for high performance MMCs. Interfacial bonding between the aluminium matrix and B_4C reinforcement seems to be better than that between the aluminium matrix and SiC.

Table 2 Comparison of Silicon Carbide and Boron Carbide Properties

Property	Unit	SiC	B_4C
Density	g/cm^3	3.21	2.51
Melting Point	° C	2,760	2,450
Hardness	Vickers	2,600	3,000
Compressive Strength	MPa	2,200	2,800
Young's Modulus	GPa	410	450
Fracture Toughness	K IC $MPam^{1/2}$	3.2	3.0
Electrical Resistivity	ohm.m	10^3-10^4	10-10^3
Thermal Expansion Coefficient	10^{-6} K^{-1}	4.0	4.6
Thermal Conductivity	$Wm^{-1}K^{-1}$	110	35
Thermal Shock Resistance	-	Good	Poor
Temperature of Application (in Air)	° C Max	1,600	500

The Al/SiC/B_4C- MMCs is one of the hybrids composite among metal matrix composites, which have silicon carbide and boron carbide particles with aluminium matrix. The silicon carbide is harder than tungsten carbide and boron carbide particles provide high wear resistance.

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Today the modern industry are rapidly introducing different composites due to their unique properties such as low density and very light weight with high strength, hardness, and stiffness, high fatigue strength and wear resistance, in order to meet the challenge of liberalization and to maintain global competitiveness in the market. Side by side modern manufacturing engineers are also trying to introduce the better properties in the composite like hybriding our usually available conventional composites. The hybrid metal matrix composites like Al/ (SiC + B_4C) are used for improve the tribological properties. The wear resistance of Al/SiC/B_4C composites increases with increase of the boron carbide particle size. The improvement of wear resistance is mainly attributed to the enhancement of integrity of lubrication tribo-layer composed of a complex mixture of boron carbide as well as SiC particle and some fine particles containing aluminium. From literature review, it is understood that the researchers have been used various methods to machine composite materials but the production of complex shapes, groves, blind holes, dovetail slots and complex contours with high dimensional accuracy on Al/SiC/B_4C-MMCs parts have also been difficult to obtain with conventional machining processes. Form the paper it is clear that machining of MMCS are very much difficult than the monolithic materials by different machining techniques. For machining the MMCs the basic requirement is that cutting tool materials should be harder than the work piece materials. In case of machining Al/SiC/B_4C-MMCs, the reinforced SiC particles, are harder than tungsten carbide which itself is a common cutting tool materials in most of cutting operations of hard materials. The selection of cutting tool material and method of machining for Al/SiC/B_4C-MMCs is very much difficult due to very high hardness value and stiffness. Aluminium/silicon/boron composite can be used in automobile components like piston, cylinder block for engine in automobile which operates at temperature up to 300^0 C. Still there are few research papers are available on traditional and non-traditional machining of Al/SiC/B_4C-MMC, so lot of research on conventional and non-conventional machining process is required, to explore the successful utilization of the process parameter during conventional machining of Al/SiC/B_4C-MMC in depth experimental analysis is to be carried out for controlling various parameter e.g. Cutting speed, cutting feed, depth of cut, cutting force, etc. on the different machinability criteria like material removal rate, surface roughness and other accuracy feature so as to find out the optimal machining condition. To meet the above requirement, the CNC milling machine is employed for machining the advance metal matrixes composite.

III. LITERATURE REVIEW

Since there are number of good researches are being made to machine aluminium metal matrix composite using various machining process in the practical materials machining field. Some of the researches works are reviewed and reported in the area are described here in after. Sahin Y. and Kok M. *et al.* [1] studied the tool wear and surface roughness of Al/Al_2O_3-MMC. The impact of machining parameters such as cutting speed, feed and depth of cut on the cutting force and surface roughness criteria were investigated. Through SEM micrographs Built up edge (BUE) and chip formation at different set of experiments were examined. Author concluded that the life of the tool is decreases with increasing the cutting speed. The surface roughness is increased with increasing the reinforcement content. The life of TiN tool is significantly longer than that of the TP30 tool. Kok M. and Ozdin K. *et al.* [2] investigation of sliding wear behavior of an Al_2O_3particle reinforced 2024 aluminium alloy composite indicated that the addition of Al_2O_3 particle size and content to the 2024 Al alloy caused a marginal decrease in the wear rate, even though the hardness of the composite almost double because of the reinforcement. Ali kalkanli and SencerYilmaz*et al.* [3] Synthesis and characterization of aluminium alloy 7075 reinforced with silicon carbide particulates. Experiments concluded that flexural strength increased with increasing the reinforcement content up to 10% SiC and it's also showed enough to attain full strength. Peak hardness values are obtained by T6 heat treatment. Suresh Kumar Reddy N. and Minyang Yang *et al.* [4], experimentally investigated the surface integrity during end milling of Al/SiC-MMCs. Experiment concluded that the surface roughness is decreased with increasing cutting speed and hardness of machining surfaces increased with increasing cutting speed, feed and depth of cut. Author found that proper selection of parameters enhanced the machining of Al/SiC and the end milling process becomes more economical and viable for its use in wide variety of industries. Manoj single and Deepak dwivedi D. *et al.* [5] studied the behavior of composite by adding weight fraction of silicon carbide (10%, 15%, 20%, 25% and 30%) to the Al 6061. The experiment concluded that the hardness and impact strength are increased with increasing the percentage of Sic. Author found that the best results are obtained at 25% weight fraction of SiC (maximum hardness = 45.5 BHN & maximum impact strength = 36 N-m). Riaz Ahamed A. and Paravasu Asokan.*et al.* [6] experimentally investigated the drilling of hybrid metal matrix composite (Al/SiC/B_4C). The test was conducted on vertical drilling machine with a HSS drill of 5 mm in diameter. Experiment concluded that the wear of HSS tool increased with increasing the cutting speeds. Cutting speed is the key factor, which has greater influence on surface roughness. Author found that cutting conditions for minimum tool wear are speed 315 rpm and feed 0.315 mm/rev and cutting condition for improved surface finish are speed 160 rpm and feed 0.125 mm/rev. Seeman M. and Ganesan G. *et al.* [7] studied the machinability of Al/SiC_p-MMCs. The impact of machining parameter such as cutting speed, feed and depth of cut, machining time on the surface roughness and tool wear were investigated. The machining parameter of turning process are molded and analyzed by using the response surface methodology. Experiment concluded that the surface rough is low at high speed and lower feed rate. The surface roughness increased with increasing depth of cut. Author found that optimum machining parameter have been obtained at cutting speed of 50 m/min, feed rate 0.05mm/rev, depth of cut 0.84mm and machining time of 2.4 min with minimum flank wear 0.283 mm and surface roughness of 1.8075µm. Sasimurugan T. and Palanikumar K. *et al.* [8] experimentally investigated the influence of cutting parameter of lathe during machining of hybrid aluminium metal matrix composite (Al6061-SiC-Al_2O_3). The hybrid composite were fabricated by stir casting method.

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The hybrid composite was turned using poly crystalline diamond inserts which is capable of providing a useful tool life during machining. Experiment concluded that the surface roughness is reduced by increasing cutting speed. The minimum surface roughness is achieved at cutting speed of 60m/min, feed rate of 0.20mm/rev and depth of cut of 0.50mm.Author found that feed rate is the highly influential parameter which influences the surface roughness in machining of hybrid composites. Muthukrishnan N. and Paulo Davim J. *et al.* [9] experimentally studied the machinability of Al/SiC- MMC by utilizing medium duty lathe using polycrystalline diamond **(**PCD) insert. Experiment concluded that the best surface finish is obtained at higher cutting speed with low feed rate. Through toolmakers microscope wear of the tool are examined. Author found that the wear during machining Al/SiC-MMCs take place on the flank of the tool. Increasing the surface finish and minimization of tool wear are possible during machining of MMCs at higher cutting speed. Power consumed is less at higher cutting speeds due to less friction between the tool and work piece interface. ArunPremnath A. and Alwarsamy T. *et al.* [10] shows that aluminium composites with multiple reinforcements are finding increased application s because of improved mechanical and tribological properties and hence are better substitutes for single reinforced composites. The hybrid composite ($Al/Al_2O_3/Gr$) are fabricated by stir casting with varying alumina weight fraction of 5, 10, 15% and graphite with constant weight fraction of 5%. The hybrid composite (Al/Al2O3/Gr) are machined using CNC milling machine. In this study, response surface method, powerful tool for experiment design was used to optimize the cutting parameter for effective surface finish. Experiment concluded that the cutting speed is the major factor influences the surface roughness with little influence caused by feed rate and weight fraction of Al_2O_3. Author found that surface roughness is decreased with increasing the cutting speed and weight fraction of alumina, its increase with increase feed rate. Uvarja V. and Natarajan N. *et al.* [11] studied the frictional and wear behavior of hybrid metal matrix composite ($Al/SiC/B_4C$). Sliding Wear test have been performed to study the influence of SiC particulates, applied load, sliding speed, and sliding time on the wear of hybrid composite specimens with combined weight fraction of SiC(5%, 10%, &15%) and B_4C(3%). In this study, the Taguchis method, a powerful tool for experiment design was used to optimize the wear parameter. Experiment concluded that the wear rate are mainly depends on the factor like percentage of reinforcement, applied load, sliding speed and time. ANOVA test concluded that percentage of reinforcement increases the wear rate and co-efficient of friction. Author found that 4.5 m/s sliding speed, 10 N applied load, 5 minutes sliding time, and 15% of reinforcement are the optimum condition for both wear and co-efficient of friction. Pragnesh R. and Petal B. *et al.* [12] experimentally investigated the effect of machining parameter on surface roughness and power consumption for Al/TiC -MMCs. Author used full factorial design in design of experiment technique to planning the experimental runs. Percentage of contribution of each process parameters on output response are investigated using analysis of variance. Author found that feed rate is significant parameter, which affect the surface roughness. The increase of feed rate increases the surface roughness. Cutting speed is effective parameter which affect on power consumption. Mahesh Babu and Aldrin Sugin *et al.* [13] experimentally investigated the surface quality on machining of hybrid metal matrix composite in Lathe. The material used in this study is aluminium matrix reinforced with SiC 10% by weight and 5% of B_4C. The hybrid composite was machined using poly crystalline diamond insert. Taguchi method was adopted for process optimization. Experiment concluded that the feed rate is the dominant parameter for surface roughness followed by cutting speed. Author found that 90m/min of cutting speed, 0.1mm/rev of feed rate, 0.5 mm of depth cut are the optimum machining condition. Wang T. and Xie L.J. *et al.* [14] experimentally investigated the surface integrity of high speed milling of Al/SiC-MMCs. Author used factorial design in Design of Experiment technique to find the impact of machining parameters. It was concluded that milling speed has the highest influence on surface roughness followed by interaction between milling speed and feed rate. Depth of cut has the highest influences on surface residual stress, followed by milling speed and feed rate. Rajkumar K. and Maria Antony Charles J. *et al.* [15] studied the machining characteristics of metal Matrix Composite (Al/B_4C). Author found that the hardness of material is increased as reinforcement added with aluminium and cutting force are high when machining with higher depth of cut & increasing in feed rate. Gopal Krishna U B. and Sreenivas Rao V. *et al.* [16] analyzed the effect of boron carbide reinforced with aluminium matrix composites (Al/B_4C) and concluded that the hardness are increased with increasing the particle size and weight fraction percentage. Sourabh Gargatta and Rahul R. *et al.* [17] sliding wear test have been performed to study the influence of SiC particulates, load, sliding speed, and sliding distance on the wear of aluminium composite specimens with percentage reinforcement of 3%, 5%, and 7% particulate. Taguchi method is used for process optimization. Experiment concluded that the sliding speed has major factor on wear of the composite and also wear arte decrease with increasing the reinforcement percentage of SiC particles. Author found that hardness of Al-5083 increased considerably with increase in SiC particle upto 7 wt. %.

IV. DISCUSSION

From the literature review, it is clear that there is essential to select proper machining process for effective machining of hybrid composites ($Al/SiC/B_4C$). There is no sufficient number of literature on machining hybrid is available, but form the published research work it is clear that Al/SiC-MMC machining is one of the major problem, which resist its wide spread application in industry. Some of the problems are encountered during machining of Al/SiC metal matrix composites are

- Very poor surface finish
- Irregular metal removal rate
- Rapid tool wear rate
- Difficult to machining very complex shapes.

V. CONCLUSION

From the above literature survey, it is noticed that there is essential need to select proper machining process for effective machining of hybrid $Al/SiC/B_4C$-MMC. From the published research work it is clear that Al/SiC-MMC machining is one of the major problem, which resist its wide spread application in industry. CNC milling machine can help to obtain the desire result.

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