Current Research Developments in Machining of Hybrid Metal Matrix Composites: A Review

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Abstract:In the past few years, research work in materials has shifted towards composite materials to meet the requirements of modern industry like higher strength, low weight, high hardness, low density, and less wear. Aluminum metal matrix composites (MMCs) are appropriate material for any industry which satisfies these requirements. They are used in several applications such as cylinder block liners, vehicle drive shafts, automotive pistons, and bicycle frames [1, 2]. In several such kinds of applications, nontraditional machining process, like electric discharge machining, is being employed for easy machining of aluminum based metal matrix composite [3, 4]. In EDM process, machining parameters have influences more on the output responses. Obtaining maximum material removal with minimum electrode wear ratio is the demand of manufacturing industry.

The study presents the review for optimal machining condition that can be used for maximize material removal rate, minimize tool wear rate and Surface roughness. The influence of EDM process parameters on performance parameters such as material removal rate (MRR), tool wear rate and Surface roughness in EDM of Hybrid Metal Matrix Composite materials has been notified as the significant findings.

Keywords:*EDM, Hybrid Metal Matrix Composite materials, EDM process parameters, Performance Parameters*

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I. INTRODUCTION

MetalMatrix Composites (MMCs) are composed of a metalmatrix and a reinforcement, or filler material, whichconfers excellent mechanical performance, and can beclassified according to whether the reinforcement iscontinuous (monofilament or multifilament) ordiscontinuous (particle, whisker, short fiber or other).The principal matrix materials for MMCs are aluminumand its alloys. To a lesser extent, magnesium andtitanium are also used, and for several specializedapplications a copper, zinc or lead matrix may be employed. MMCs with discontinuous reinforcements are usually less expensive to produce than continuous fiberreinforced MMCs, although this benefit is normallyoffset by their inferior mechanical properties.Consequently, continuous fiber reinforced MMCs aregenerally accepted as offering the ultimate in terms ofmechanical properties and commercial potential.

The UK.s Advisory Council on Science & Technology in1992 stated that MMCs can be viewed either as areplacement for existing materials, but with superiorproperties, or as a means of enabling radical changes insystem or product design. Moreover, by utilizing near-netshape forming and selective reinforcement techniquesMMCs can offer economically viable solutions for a widevariety of commercial applications.In general, the major advantages of Aluminum MatrixComposites (AMCs) over monolithic materials e.g. iron,steel and other non-ferrous common metals are asHigh specific strength,High specific stiffness, Higher elevated temperature strength, Improved wear resistance, Low density; high strength to weight ratio, Improved damping capabilities, Tailor able thermal expansion coefficients, Good corrosion resistance etc.

When at least three materials are present, it is calleda **hybrid composite**. Al/SiC/Grp-MMC is one of theimportant hybrids composite among MMCs, which haveSiC& Gr particles with Aluminum matrix. The SiC isharder than Tungsten carbide (WC) and Graphiteparticles provide high resistance to wear in the hybridcomposite. Recently modern industry rapidly introducingdifferent composites due to their unique properties suchas low density and very light weight with hightemperature strength, hardness and stiffness, high fatiguestrength and wear resistance, in order to meet thechallenge of liberalization and to maintain globalcompetitiveness in the market. Side by side modernmanufacturing engineers are also trying to introduce thebetter properties in the composite like, hybriding ourusually available conventional composites such asAl/SiC-MMC, Al/Grp-MMC, Al/Al2O3-MMC etc.

Thehybrid metal matrix composite like Al/(SiCp + Grp)-MMC is one of the composites which have many uniqueproperties over Al/SiC-MMC or Al/Grp-MMC. The wearresistance of Al/SiC/Grp composites increases with theincrease of the graphite particle size. The improvement ofwear resistance is mainly attributed to the enhancementof integrity of lubrication tribo-layer composed of acomplex mixture of graphite as well as fractured SiCparticles and some fine particles containing aluminum.The aluminum alloy, reinforced with discontinuousceramic reinforcements, is rapidly replacing conventionalmaterials in various automotive, aerospace andautomobile industries. Most of the parts obtained withAluminum matrix composites through differentmanufacturing processes namely the process derivedfrom the casting have different geometry and they usuallyneed machining operations with the required dimensionaland geometrical precision as well as good surfaceroughness (SR).Although still only few research papers are available ontraditional and non-traditional machining of Al/SiC/Grp-MMC, hence a lot of applied research on traditional andnon-traditional machining processes is required toexplore the successful utilization of the processparameters during the non-traditional machining ofAl/SiC/Grp-MMC.

To explore the potential utilization ofthe non-traditional machining process in the area ofAl/SiC/Grp-MMC machining, in-depth experimentalanalysis is to be carried out for the controlling variousmachining parameters e.g. pulse on time (TON), pulsepeak current (IP), Duty cycle (ô), Gap voltage (Vg), Pulsepause time (TOFF), Tool/ Electrode polarity etc. on thedifferent machinability criteria like material removal rate(MRR), electrode wear rate (EWR), surface roughness(SR), and other accuracy features so as to find out theoptimal machining condition. To meet the aboverequirement of machining of advance metal matrixcomposite, the EDM machining method is to beemployed.

II. LITERATURE REVIEW

Manna A. and Bhattacharyya B. (2003) studied themachinability of Al/SiC-MMC. The impact of machining parameters such as cutting speed, feed and depth of cuton the cutting force and surface roughness criteria wereinvestigated. Through SEM micrographs BUE and chipformation at different sets of experiments were examined.Author concluded that flank wear rate is aversivelyproportional to cutting speed due to generation of highcutting force and formation of BUE.

Manna A. and Bhattacharyya B. (2006), experimentallystudied the machinability of Al/SiC-MMC by utilizingCNC-Wire cut EDM. Authors studied the variousparameters of WEDM during machining and establishedthe optimum combination of WEDM parameters fordifferent performance criteria. It was concluded that lowinput pressure of dielectric is not sufficient to remove thereinforced particles during machining. Open gap voltageand pulse on-time are the most significant andinfluencing machining parameters for controlling thematerial removal rate.

K.M. Patel et.al.[2009] derived quadratic mathematical model to represent the process behaviour of EDM. Experiments has been conducted with four process parameters viz. discharge current, pulse on time, duty cycle and gap voltage and to relate them with process response surface roughness (SR). Experiment was performed with AL2/SiCW/TiC ceramic composite as workpiece. Response surface method has been found efficient for prediction of process response for various combinations of factor setting. The significance of machining parameters selected has been established using analysis of variance. The surface roughness prediction model has been optimized using a trust region method. It was concluded that Pulse-on time is found to be the dominant parameter influencing surface roughness (SR) and it was also observed that an increase in discharge current increases the SR. The confirmation test showed that developed models can predict the SR accurately within95% confidence interval.

Adrian Iosub, EugenAxinte, Florin Negoescu (2010),gave the influence of the most relevant parameters ofElectrical Discharge Machining over material removalrate, electrode wear and machined surface quality of ahybrid metal matrix composite material (Al/SiC) hasbeen carried out. The material used in this study isaluminum matrix composite reinforced with 7 % SiC and3.5 % graphite. The hybrid composite was machinedusing 27 brass tools with Ø = 3.97 mm. Different pulseon-times (ton), pulse off time (toff) and peak current values(Ip) was used for each electrode. For the experiments, afull factorial design was used. Regression analysis wasapplied for developing a mathematical model. The hybridSiC/Al composite material can easily be machined byEDM and a good surface quality can be obtained bycontrolling the machining parameters.

L. Krishnamurthy, B.K. Sridhara, D. Abdul Budan(2011), presented the result of an experimental investigation onthe comparative machinability of aluminum-siliconcarbide composites and aluminum-graphite-siliconcarbide hybrid composites during turning using carbidetool inserts. The experiments were carried out basedon central composite design of experiments approach.The influence of machining parameters viz. cuttingspeed, feed and depth of cut on the resultant force hasbeen analyzed statistically. It is established that hybridcomposites have better machinability when compared toaluminum-silicon carbide composites.

S. Gopalakannanet. al. [2012] investigated the influence of process parameters and their interactions viz., pulse current, gap voltage, pulse on time and pulse off time on MRR, EWR and SR. Experiments were carried out to machine newly engineered metal matrix composite of aluminum 7075 reinforced with 10% of B4C particles using copper as electrode. Response Surface Methodology had been employed to develop mathematical model and to establish empirical relationships between process parameters and process responses. Analysis of variance was carried out to validate the experimental results. It was concluded that the two main significant factors that affects the MRR are pulse current and pulse on time. The MRR first increases and then decreases with increasing pulse on time. The surface roughness increases with increase in pulse current and pulse on time & surface roughness decreases upto 50 volt and then increases with further increase in voltage.

R. M. Arunchalamet. al. [2012] the machinability evaluated through the response surface methodology in machining of homogenized 10% micron Al_2O_3 LM25 MMC manufactured through stir casting method. The combined effects of three machining parameters including cutting speed (s), feed rate (f) and depth of cut (d) on the basis of three machining characteristics of tool wear, surface roughness were investigated. The contour plots were generated to study the effect of process parameters as well as their interactions. The process parameters were optimized using desirability based approach response surface methodology.

Kumar et. al. [2013] optimized the parameters of WEDM process by considering the effect of input parameters viz. pulse on time, pulse off time, wire speed and wire feed on process responses viz. MRR and SR while machining Al-sic (20%) plate using molybdenum wire. The RSM quadratic mathematical model was utilized to represent the process responses as a function of process parameters. The Taguchi method was used for minimizing the surface roughness. It was found that factors like pulse on time, pulse off time, wire speed and wire feed play a significant role for material removal rate and surface roughness.

S. Gopalakannanet. al. [2013] investigated the influence of process parameters and their interactions viz., pulse current,

gap voltage, pulse on time and pulse off time on MRR, EWR and SR. Experiments were conducted by choosing the typical process parameters such as pulse current, gap voltage, pulse on time and pulse off time. The taguchi based grey relational analysis was adopted to obtain grey relational grade for EDM process with multiple characteristics namely material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). thesignificance of process parameters was obtained by analysis of variance based on grey relational grade, which showed pulse current and pulse on time to be the most sign cantparameters.

S. Suresh Kumar et. al. [2014] investigated EDM parameters of Al alloy (Al6351) matrix reinforced with 5wt.% silicon carbide (SiC) and 10 wt. % boron carbide (B_4C) particles fabricated through stir casting route. Multiresponse optimization was carried out through grey relational analysis (GRA) with an objective to minimize the machining characteristics namely electrode wear ratio (EWR) and surface roughness (SR) and power consumption (PC). The optimal combination of input parameters was identified, which showedthe significant enhancement in process characteristics. Contributions of each machining parameters to the responses were calculated using analysis of variance (ANOVA). The result showed that the pulse current contributes more (83.94%) to affecting the output responses.

J. Laxmanet. al. [2014] optimized the parameters of EDM process using the grey relational analysis based on an orthogonal array for multi response process. The experiments were conducted on titanium super alloys with copper electrode based on taguchi design of experiments L27 orthogonal array by choosing various parameters such as peak current, pulse on time, pulse off time and tool lift time for EDM process to obtain multiple process responses namely metal removal rate and tool wear rate. The result showed that the pulse current was the most influencing factors for machining of Titanium super alloys.

Gurpeet Singh et. al. [2014] studied the effect of machining parameters of Al/Sic/Gr MMC components on cutting forces. In these experiments, hybrid Al/Sic/Gr MMC samples were prepared with by stir casting method. The effect of cutting speeds, feed rates and depth of cut on cutting forces were investigated in the turning operation of hybrid Al/Sic/Gr MMC. Machining operations were conducted using uncoated tungsten carbide tool. The result of experimentation showed that change in depth of cut was the maximum effect on the cutting forces than feed rate and speed.

Table: Contributions of various authors in the field of Hybrid metal matrix composites.

Sr. No.	Name of Researchers	Year	Contribution	Work piece material	Parameters	
					Machining	Performance
01	Manna A. and Bhattacharyya B.	2003	Studied the machinability of Al/SiC-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.	Al/SiC-MMC.	cutting speed, feed and depth of cut	cutting force and surface roughness
02	Manna A. and Bhattacharyya B.	2006	experimentally studied the machinability of Al/SiC-MMC by utilizing CNC-Wire cut EDM. Authors studied the various parameters of WEDM during machining and established the optimum combination of WEDM parameters for different performance criteria	Al/SiC-MMC	Gap voltage, current, pulse on time	MRR, SR
03	K. M. Patel et. al.	2009	Investigated the determination of an Optimum Parametric Combination Using a Surface Roughness Prediction Model for EDM of Al_2O_3/SiCw/TiC Ceramic Composite	Al_2O_3/SiCw/TiC Ceramic Composite	Discharge current, Pulse on time, Duty cycle, Gap voltage	SR
04	Adrian Iosub, EugenAxinte, Florin Negoescu	2010	Determined the influence of the most relevant parameters of Electrical Discharge for Hybrid metal matrix composite material (Al/SiC).	hybrid metal matrix composite material (Al/SiC)	process parameters	material removal rate, electrode wear and

						machined surface quality
05	L. Krishnamurthy, B.K. Sridhara, D. Abdul Budan	2011	Presented result of an experimental investigation on the comparative machinability of aluminum-silicon carbide composites and aluminum-graphite-silicon carbide hybrid composites during turning using carbide tool inserts.	machinability of aluminum-silicon carbide composites and aluminum-graphite-silicon carbide hybrid composites	Process parameters	Output
06	S.Gopalakannan et. al	2012	Studied the modeling and optimization of EDM Process Parameters during the Machining of Al 7075-B_4C MMC by using RSM	Al 7075- B_4C MMC	Pulse current, Gap voltage, Pulse on time, Pulse off time	MRR, EWR, SR
07	R. M. Arunchalam et. al.	2012	In this work, the machinability evaluated through the response surface methodology in machining of homogenized 10% micron Al_2O_3 LM25 MMC manufactured through stir casting method.	10% micron Al_2O_3 LM25 MMC	cutting speed (s), feed rate (f) and depth of cut (d)	tool wear, surface roughness
08	Kumar et. al.	2013	Studied the modeling and optimization of Wire EDM Process during the machining of Al-SiC (20%)	Machining Al-SiC (20%)	Pulse on time, Pulse off time, Wire speed, Wire feed	MRR, SR
09	S.Gopalakannan et. al	2013	Investigated the statistical optimization of EDM parameters on machining of aluminum Hybrid metal matrix composite by applying Taguchi based Grey analysis.	aluminum Hybrid metal matrix composite	Pulse current, Gap voltage, Pulse on time, Pulse off time	MRR, EWR, SR
10	S. Suresh Kumar et. al.	2014	Studied the Electrical Discharge machining parameters for Al (6351)- 5% SiC-10 % B_4C Hybrid Composite by using A Grey Relational Approach	Al (6351)- 5% SiC-10 % B_4C Hybrid Composite	Discharge current , Pulse on time, Duty cycle, Gap voltage	EWR, SR and PC
11	J. Laxman et. al	2014	optimized EDM process parameters on Titanium Super Alloy by using Grey Relational analysis	Titanium Super Alloy	peak current, pulse on time, pulse off time and tool lift time	MRR, TWR,
12	Gurpeet Singh et. al.	2014	Studied the optimization of cutting forces during turning of Al/SiC/Gr hybrid Metal Matrix Composite	Al/SiC/Gr hybrid Metal Matrix Composite	cutting speeds, feed rates and depth of cut	cutting forces

III.CONCLUSION

The literature review reveals thatthe current research development in machining of hybrid metal matrix composites followed by the progress of EDM technology. The effectiveness of Electro discharge machining process is usually evaluated on the basis of their response varibles. In EDM, machining parameters have effectmore on the response varibles.This works help to identify the most

influential machining parameters and technique used to determine the optimum combination of machining parameters.

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