Effect of Turning Parameters on Aluminium Metal Matrix Composites - A Review

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Abstract: Metal matrix composites have good mechanical properties as comparison to metals during various operations. Hence, different engineering applications started using MMC a very good choice in substituting metals. The paper provides a review on turning of strengthened aluminium metal matrix composites (AMMC) particularly reinforced particles. Also paper highlights the recent development of reinforced MMC from glass fiber reinforced polymers to present day hybrid and nano-composites. The paper is also showing the effect of different machining parameter on the response variables like surface roughness, tool wear rate, and material removal rate.

Key words: AMMC, MMC, CVD, Reinforcement, Cutting speed, Feed, Depth of cut, Surface finish, Machinability etc.

1. INTRODUCTION
Composite materials have different physical as well as chemical properties and are insoluble in each other [1]. The Materials for matrix and reinforcement will either be organic, inorganic or metallic etc. The commonly used reinforcement materials are fibers or particulates. Composite materials have good specific properties such as high strength, stiffness, good fatigue, high heat resistant, high wear resistant, high corrosion resistant, low weight and superior mechanical properties for several engineering applications. Matrix materials in Metal Matrix Composites (MMC) are aluminium, magnesium and titanium alloys. Reinforcing materials in MMC are oxide, carbide and boride within the style of particles, short fibers (whiskers) or long fibers. In aluminium Metal Matrix Composites (AMMC), matrix material is aluminium and reinforcement materials are SiC, Al₂O₃, B₄C, graphite etc. This paper discusses the important features of machining of MMC particularly the aluminium metal matrix composites.

2. LITERATURE REVIEW
L. A. Looney, J.M. Monaghan, P.O. Reilly and D. M. R. Taplin conducted turning tests during which variety of different cutting tool such as carbide (coated & uncoated) CBN tools were used to machine an Al.25 volume % SiC MMC. The result showed that cutting speed on tool wear and surface finish established for every tool material. They found that carbide tools (coated and uncoated) wear very short duration as compared to CBN.
J.E. Caroline, Andrewesa, Hsi-Yung Fenga, W. M. Laub studied the machining of Al MMC with SiC (20%) using brazed polycrystalline diamond (PCD) tools, and chemical vapour deposition (CVD) diamond coated tools on CNC lathe machine. The results showed that the initial flank wear of PCD and CVD tools was occurred by abrasion because very hard SiC particles present in work piece material.

Davim P.J. studied on the influence of cutting parameters (cutting speed and feed) and cutting time on turning metal matrix composites (MMC). Experimentation was conducted using Taguchi technique. Associated orthogonal array and analysis of variance (ANOVA) were used to analyze the cutting characteristics of MMC using PCD tools. They found that the cutting speed has the best physical as well statistical influence on the tool wear (42.3%) and feed shows highest physical as well statistical influence on the surface roughness (32.5%).

X. Ding, W. Y. H. Liew, X. D. Liu studied the performance of polycrystalline cubic nitride chemical compound (PCBN) and polycrystalline diamond (PCD) cutting tools for turning of Al alloy MMC strengthened with assaill on CNC shaping machine. Throughout turning, the PCBN tools were fracture, and therefore the quantity of material stick onto the tool. PCD tools have higher performance than PCBN tools.

Basheer et al. studied the modelling of surface roughness in fine machining of MMC with Artificial Neural Network (ANN). They investigated roughness of machined surfaces on Al-SiC composites associated developed of an ANN-based model to predict surface roughness on CNC turning with PCD tool. They found that the most effective surface quality was obtained at lowest feed-rate, the smaller particle size and therefore the largest tool-nose radius.

T. Ozben, Erol Kilickap, Orhan C., akır investigated mechanical and Machinability properties of SiC particle reinforced Al-MMC. Machining tests of specimens were carried out in typical lathe machine using TiN coated hard carbide (K10) tool. They found that with increase in reinforcement ratio, increases tensile strength, hardness and density of AlSi7Mg2-MMC material and impact toughness decreased. Flank wear of tool vary with reinforcement ratio. Increase in feed rate resulted into tool wear and surface roughness.

R. Shetty, Raghuvin B. Pai Shrikanth S.Rao, Rajesh Nayak studied to optimize cutting parameters in turning of age hardened Al6061-15% vol.SiC MMC with CBN tool and steam as a cutting fluid. Taguchi and ANOVA technique was used to study the effect of process parameters on machining. They found that among all parameters, steam pressure was the most important parameter that has highest physical and statistical significance.

J.Paulo Davim, N. Muthukrishnana studied on optimisation of machining parameters of AlSiC-MMC with ANOVA and ANN technique for analysis. A medium duty lathe machine with 2Kw spindle power was used to perform the experiments with PCD coarse grade tool, surface roughness under different cutting conditions data was collected for varied mixtures of cutting speed, feed rate, and depth of cut. The PCD tool with CNMA 120408 inserts and PCLNR 25X 25 M12 tool holders were used for turning of 150mm diameter work piece. ANN methodology takes lesser time for giving higher accuracy. Therefore, optimisation with ANN is that the simplest technique compared with ANOVA. They found that in ANOVA, the
feed rate has highest physical as well as statistical influence on the surface roughness (51%) right when the depth of cut (30%) and therefore the cutting speed (12%).

Kirby mentioned on investigation into optimizing a quality characteristic, whereas considering productivity, through the use of Taguchi parameter design. A turning operation was the topic of their study, and therefore the output parameter selected was surface roughness. It had been found that the feed rate and spindle speed had vital effects on surface roughness, whereas depth of cut had associate insignificant result. The noise factors were not found to be statistically vital with the given sample size, though they might still be thought of very important to produce necessary variance to form this experiment strong.

S. P. Dwivedi, Sudhir Kumar and Ajay Kumar studied the result of turning parameters like cutting speed, depth of cut and feed rate on surface roughness of A356-SiC 5% composite created by electromagnetic stir casting. Turning of A356 alloy 5 wt% SiC composites was carried out by tungsten carbide inserts on CNC lathe machine. They found that cutting speed increases surface roughness decreases, whereas depth of cut and feed increase surface roughness increase.

A. Srinivasan, Arunachalam R.M., Ramesh S., Senthilkumara J.S. studied machining of homogenized 10% micron Al2O3 LM25 Al.MMC was manufactured by stir casting technique. The experiments were conducted on Kirloskar all geared lathe machine with uncoated cemented carbide tool. The machining parameters for turning process were optimized using Taguchi method for minimizing the tool wear, surface roughness and cutting force. They concluded that the tool wear increases with increase of the cutting speed, the feed and therefore the depth of cut and cutting speed has the foremost dominant result on tool wear. The surface roughness improves with increase the cutting speed whereas by increasing feed surface roughness decreased.

Aramesh et al. Experimented on Ti-6Al-4V alloy matrix strengthened with 10-12% of TiC ceramic particles was used. Dry machining tests were conducted on a CNC turning centre, equipped with a dynamometer for force measurement. Coated carbide inserts tool (TiSiN-TiAlN nano-laminate PVD coated grades) with nose radius of 0.8 mm were used. Multi objective optimisation technique has been performed to search out minimum tool wear and surface roughness.

P. Shanmugasundaram and R. Subramanian studied influence of graphite and machining parameters on the surface roughness of Al-fly ash/graphite hybrid composite using multi-coated carbide tool with a 0.8 mm nose radius on CNC lathe machine. Taguchi and ANOVA techniques in turning of Al, Al-15 wt% fly ash and Al-15 wt% fly ash /1.5 wt% composites for optimizing cutting speed, feed and depth of cut .They concluded that the presence of the ash particles reduces the surface roughness of composites compared with pure Al. The feed rate (46.96%) has the very best influence on surface roughness within the machining of an Al-fly ash/Gr composite followed by cutting speed (43.35%) and depth of cut (5.58%).

P. Bansal, Lokesh Upadhyay fabricated homogenized (2%, 4% and 6%) Al203 Al.MMC, and select it as work piece for experimental investigations of TWR, Ra and MRR using Taguchi technique. The titanium nitride coated tungsten carbide tools and uncoated tungsten carbide
tools were used at completely different cutting speeds (265,400,535 rpm), feed rate (0.29, 0.32, 0.35 mm/rev) and depth of cut (1.0, 1.5, 2.0 mm). They concluded that the lifetime of coated tools is quite the uncoated tools. The tool wear rate increases by increasing the reinforcement ratio. The cutting speed is the main parameter that affects the TWR, Ra and MRR. Owing to abrasive reinforcement part corundum, causes more wear on cutting tools. Feed rate is variable with tool wear, as feed rate increases, the wear of cutting tool also increases. It has been ascertained that a rise in reinforcement ratio increase in surface roughness.

A.K. Sahoo, S.Prudhan, A.K.Rout studied development of Al/SiC 10% metal matrix employing a typical casting method and studied its machining parameters on lathe machine using multilayer TiN coated carbide tool under dry condition. From the experimental study using Taguchi’s L9 orthogonal array they found that cutting speed was the foremost affecting parameter on the flank wear. Feed was found to the next important parameter for surface roughness. Surface roughness increases with increase of feed up to 0.1 mm/rev. At above 0.15 mm/rev feed, the surface quality decreases continuously.

A. Kumar Sahoo, Swastik Pradhan Studied the influence of process parameters like cutting speed, feed and depth of cut on flank wear and surface roughness (Ra) in turning Al/SiCp MMC with uncoated tungsten carbide insert under dry condition using Taguchi technique. They found that the best constant quantity combination for flank wear found were cutting speed at 60 m/min, feed at 0.05 mm/rev and depth of cut at 0.4 mm respectively. Cutting speed was the foremost vital parameter for flank wear followed by feed. Depth of cut has the insignificant effect on flank wear.

P. Jayaraman, L. Mahesh kumar studied for optimisation of machining parameters on turning of AA 6063 T6 Al.alloy alloy with uncoated carbide insert under dry cutting condition with multiple responses based on orthogonal array with gray relation analysis. They found that feed rate and depth of cut are important factors that have an effect on turning of Al.alloy. The feed rate is the most effective factor in determining the gray relative grade (GRG) followed by depth of cut and cutting speed.

J. James. S, Venkatesan.K, Kuppen.P, Ramanujam studied machining and mechanical properties on hybrid Al/MMC strengthened with SiC and TiB2. They found that % of TiB2 reinforcement is the simplest parameter for surface roughness and its contribution is 38.86%. Analysis prooved that TiB2 cause high tool wear, poor surface finish and settled edge formation affects surface quality. High tool wear causes by low cutting speed, high depth of cut and increased wt % of TiB2 reinforcement.

A. Saini,Suresh Dhiman, Rajesh Sharma and Sunil Setia Concluded the process parameters for AISI-4340 with PVD and CVD carbide inserts under minimum amount of lubrication and dry turning. They found that out of three cutting forces the main cutting force was maximum in case of AISI 4340 steel turning. Throughout the experiments, approach angle, cutting speed and feed rate were varied to 4 levels with constant depth of cut to analyze the result of MQL and dry turning on the 3 cutting forces.
Venkatesan et al. estimated the optimum cutting forces and surface roughness for machining of Al. alloy hybrid composite using RSM to achieve accuracy up 95%. They concluded that in case of coated carbide inserts roughness decreases at higher cutting speed throughout machining. Also found that higher percentages of reinforcement resulting in poor surface finish and consumes higher cutting energy. Mahamani studied effects of process parameters on cutting force and surface roughness during turning of AA2219-TiB2/ZrB2 uniaxial metal matrix composites on lathe machine with uncoated tungsten carbide insert. In his study, the result of cutting speed, feed rate and depth of cut on cutting force and surface roughness was by experimentally investigated using Taguchi technique. Associate L27 orthogonal array, response graph and ANOVA were used to analyze the result of turning parameters. Response graphs show that feed rate shows greater influence on cutting force and surface roughness. D.Sai Chaitanya Kishore, K. Prahlada Rao, A. Mahamanic investigated effects cutting force, surface roughness and flank wear for various cutting speed, feed and depth of cut for Al-6061, Al6061-2%TiC and Al6061-4%TiC MMC on turning lathe machine with uncoated tungsten carbide tool. They concluded that the cutting force and surface roughness were less at higher cutting speeds. Flank wear increases with increase in cutting speed and increase in feed rate and depth of cut, cutting force, surface roughness and flank wear increases.

P. Rao studied the result of machining parameters on the surface roughness throughout turning particulate composites. They compared the surface roughness achieved for composite with 10% filler material with that of K10 grade tungsten carbide insert. And found that PCD inserts gives lower surface roughness. They also show that machining of Al fly ash composites shows higher surface roughness with increase feed rate and decreased cutting speed.

M. Gupta, Surinder Kumar experimented on glass fiber reinforced plastics (UD-GFRP) by PCA and Taguchi technique with PCD insert. They concluded that feed rate is most significant factor giving higher Ra values with higher speed rate.

A. Nestler, A. Schubert studied the effect of machining parameters on surface roughness in slide diamond burnishing of Al. matrix composite AA2124 with 25% of SiC particles on a lathe machine using CVD tool. They concluded that voids and surface roughness can't be reduced. Also concluded that residual stresses generated within the surface layer were within the order of the yield strength of Al. alloy.

B. Das, Susmita Roy, R.N. Rai, S.C. Saha studied on the effect of cutting parameters on surface roughness of Al-Cu-TiC MMCs on CNC MTAB lathe machine using Taguchi and ANN approach. They studied the effect of cutting speed, feed and depth of cut on the responses like Ra, Rz and Rt of Al-4.5, Cu-1.5, TiC MMC. This research work successfully established process model to predict the surface finish and method of controlling of process parameters employed in different industrial applications.

C. Shoba, Nallu Ramanaiah, Damara Nageswara Rao mentioned the use of the Taguchi experimental design technique to search out the best parameters while machining Al/6% SiCp/6% metal matrix hybrid composites. They investigated the effect of speed, feed and depth of cut on surface roughness. Optimum set of parameters were obtained using ANOVA.
The SEM and 3D surface topography was used to investigate the worn machined surface of the hybrid composites.

3. Effect of Various Factors
Properties of AMMC are mostly depends on process parameters, matrix & reinforcement and tooling conditions. Various researchers has investigated the effect of this parameters either combined effect of one or more or separately. This effect of various factors is discussed here.

3.1) Process parameters

3.1.1. Cutting Speed
Cutting speed placed very important role in tool life. Usually it was observed that tool life moderately decreased with increase in cutting speed this is because at higher speed heat generated which soften the tool material and consequently increasing the diffusion wear [5]-[6]-[7]-[8]-[9]. On the contrary surface roughness improves with increase in cutting speed [16]-[18]-[25]. Overall the variation of surface roughness with change in cutting speed cannot be justified as the surface roughness is controlled by the presence and size of reinforcement as well as feed rate used during machining. [2]-[3]-[4]. Another observation in case of reinforce MMC is variation in flank wear because of variation in cutting speed range. Cutting speed with 60 to 100m/min with Al. matrix reinforcement with SiC Particles is recommended. [6]-[20] Researchers has also studied the formation of BUE and its effect on surface roughness tool life of MMC at cutting speed range. At higher cutting speed formation of BUE can be minimized reducing feed forces resulted in increasing in tool life. Fig.1 shows schematic representation of presence of reinforcement in MMC.

![Machining of metal matrix composites](image)

3.1.2. Feed
Feed has significant impact on the cutting forces because the cutting forces rise significantly with a rise within the feed [10]-[12]. Feed decides cutting forces and feed forces generated during machining. Many researchers predicted the forces using merchant circle and also developed energy base analytical model and mechanics based model to predict various forces.
during orthogonal cutting. Feed force deteriorates the surface finish as well as damages the sub surface with increase in feed rate value.9-11. In case of some reinforce MMC high feed rate shows the reduced tool wear rate due to improvement in the conduction of heat from cutting zone the work piece.14-15-16-18.

3.1.3. Depth of Cut
Depth of cut has great influence on tool life, feed force and surface finish. Higher feed rate has stronger impact on tool life 17. In case of surface finish, feed rate puts negative impact on the surface finish as well as sub surface. In case of MMC, too increase in feed force decreases the surface finish. Similarly, in case of tool life, higher depth of cut increases the machining forces resulted in decreasing the tool life 21. In case of MMC distribution of reinforced material in metal plays a significant role in generation of forces resulted in various surface properties.

3.1.4. Effect of Tooling
For effective machining of metals and composites, tooling gives various options like polycrystalline, carbide, diamond tip tooling, and chemical vapor deposition. Although there are various options polycrystalline diamond are most preferred for machining. High tool wear observed while machining of these composites is usually related to diamond or carbide tip. At higher cutting speeds (350m/min), the carbide tool shows catastrophic failure and thence the cutting speed is mostly restricted up to 300 m/min 1-10-11. In case of machining of MMC, cutting tool with insert shows the better tool life than coated tip cutting tools 12. Looney et.al machined at cutting conditions that sustained a stable built up edge (BUE), to protect cutting tip. To reduce the surface roughness and sub-surface damage PCD tools are preferred since the wear and tear rate related to them is that the lowest among the tool materials. Although PCD tools are used for machining Al/SiC composites, the high value related to them limits their use.2-3-4-5

3.1.5. Effect of Reinforcement
Machinability of composites is greatly influenced by presence of the reinforcement. Many a times presence of hard ceramic particles creates a problems like tool wear. The dimensions and therefore the proportion volume fraction of the reinforcement play a major role on the machinability of composites. Surface finish is mainly depend upon average size and volume fraction of the particles. Looney et al. 1 machined AN Al/SiCp composite with SiC particle size of 30, 45 and 10 µm and a reinforcement of 16% volume by coated and uncoated carbide coated tools. They found that the tool wear and surface finish are negatively affected the particle size.

Srinivasan et al. 11 studied the impact of feed (0.084–0.17 mm/rev), cutting speed (22–88 m/min), tool inclination angle (15 and 45) and proportion volume fraction of SiC. Particles in Al (10 and 30%) on machining of the MMC with a carbide tip tool and arrived at an empirical relationship between flank wear and cutting time as a operate of the said parameters. The authors concluded that the cutting speed and therefore the percentage volume fraction of the particles had the impact on the tool life.

Tensile strength of MMCs increases with the % increase in the reinforcement of alumina but the change is not much due to the presence of ceramic particles. Figure 3 shows the variation of tensile strength with the variation of reinforcement 28.
4. CONCLUSION

1) A major work has been done on Al. based MMC with Al. 5083, Al. 6061, Al. 6063, Al. 7075, Al.2024 series alloys as matrix material.
2) Abrasion is found to be the dominant wear mechanism.
3) Reinforce materials are used Al2O3, SiC, from 5% to 15% by weight.
4) PCD and PCBN tools performed better than other tools(Coated & uncoated)
5) Percentage of Ti-B2 into the matrix should be limited up to 2.5% by weight
6) If cutting speed increases it affect the surface roughness.
7) If Feed, depth of cut and cutting speed increases, MRR increases.
8) Increase in cutting speed, feed, and depth of cut, reinforce size, particle ratio, tool wear rate will increase.

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