

A Review on Turning of Metal Matrix Composites

P. G. Karad¹, D. S. Khedekar²

P.G. Student, Department of Mechanical Engineering, Jawahrlal Nehru Engineering College, Aurangabad, India¹

Asst. Professor, Department of Mechanical Engineering, Jawahrlal Nehru Engineering College, Aurangabad, India²

ABSTRACT: Metal matrix composites have entered in industry with extreme interest from the automobile and aerospace sectors due to their superior mechanical properties and applications. During last few years, researchers have uncovered many secrets relating to these advanced materials. This paper briefly reviews the research disclosures of the mechanisms that make these materials so superior. As most of the components are round in shape used in industry, turning of metal matrix composites is focused in paper. Mechanisms such as particle fracture, debonding, dislocation phenomena, thermal softening, surface generation, chip formation, strains and stresses are addressed. Discussions on related phenomena such as effects of friction, microstructures and strain hardening are also presented.

KEYWORDS: MMC's, machining, tool selection, strain hardening, machining characteristics.

I. INTRODUCTION

Turning is a machining process used to obtain the desired dimension of round metal. The main objective in present industrial era is to produce low cost quality product with required dimensions in an optimum time. Therefore the optimum cutting parameters are to be recognized first. In turning, the metal is in rotational motion and a cutting tool is used to shear away the unwanted metals. This process requires lathe or turning machine, cutting tool, work piece and fixture. The work piece is fixed in the fixture and is rotated in high speed. The cutting tool is fed in parallel to the axis of rotation as shown in Fig. 1. During this process the cutting parameters highly depends upon the work piece, cutting tool material, etc. These are determined by experience or machine hand book.

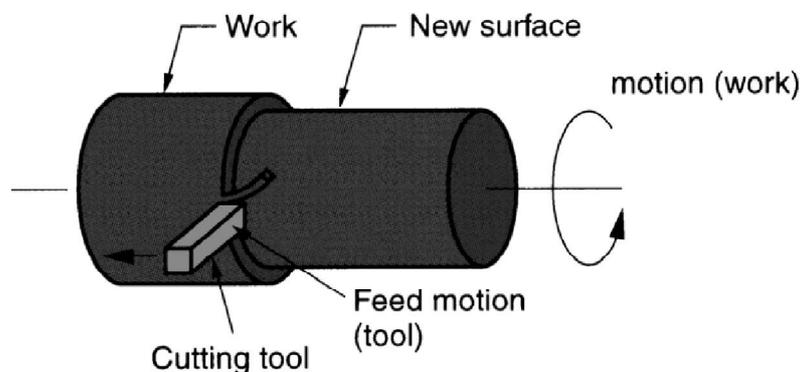


Figure 1. Turning process

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

II. METAL MATRIX COMPOSITE

Metal matrix composites (MMCs) deal remarkable opportunities for new product design due to improved properties. Some of the advantageous properties of MMCs are high strength and stiffness, increased wear resistance, dimensional stability at a higher temperature and lower coefficient of thermal expansion. Aluminium metal matrix composites (AMCs) contains aluminium/aluminium alloy as the matrix material and the other phases are reinforcement which are Gr, SiC, Al₂O₃, B₄C, etc [1, 2]. The combination of ceramic particles in Al alloy increases both mechanical strength and wear resistance of the composite. Machining becomes difficult with the hard abrasive SiC particles in Al-SiC composite. Thus the machinability of particulate MMCs can be improved by reinforcing soft particles like graphite along with hard ceramic particles [3]. There is need of advance materials which can fulfill the requirement of automotive and aerospace industries, Metal matrix composites (MMCs) are the new age materials that are being preferred for their improved properties. Compared to conventional metals and alloys, these materials gives higher strength to weight ratio, hardness, stiffness, wear resistance etc. as. However, these very properties make these material difficult to machine. That's why, many researchers have worked to unraveling various aspects of machining these composites.

2.1. Tool selection

Tool selection is important in machining metal matrix composites. Gallab and Sklad [1] performed experiments that shows the superiority of PCD tools over Al₂O₃/TiC tools due to their higher hardness and thermal conductivity, that helps heat flow away from the cutting zone. Few researchers worked similarly [2-4], where excellent chemical affinity of the MMC with the PCD is also noticed. Monaghan et al. [5] ranked various tool materials in the order of decreasing tool wear. Hung [6] reported that PCD and PCBN tools to be much better than WC tools. Tomac et al. [7] Compared chemical vapor deposition inserts (CVD) to TiN, TiCN and Al₂O₃ coated tools. They confirmed superior performance of CVD tools over the others. Weinert and Biermann [8] promoted PCD and CVD inserts in machining MMCs due to their low tool wear rates. In machining MMCs regarding thermal, hardness and fracture properties PCBN tools also fare good against ceramic and cemented carbides. Improve fracture resistance of tools binders also helped. [9]. Looney et al. [10] found that cubic boron nitride inserts shows the best machining performance in machining Al/SiC MMCs.

2.2. MMC physical properties

For reveal of MMC properties, Zhang et al. [11] prepared quantitative models for adhesive wear [13] and steady sliding [12] in wear experiment of a steel disk sliding against metal matrix composite pins. They concluded that increase in particle size was more advantageous than incrementing volume fraction in delaying wear strengthening from mild to adhesive modes. Ozben et al. [14] found that that greater SiCp reinforcement directly resulted in higher tool wear. Pramanik et al. [15] determined a correlation between cutting velocity and the strength of the composite material. Similarly, few research works shown machining temperatures at specified volume fractions, speeds, feeds and depths of cut [16]. Few researchers determined the extent of change in MMC material properties as per cutting temperatures [17]. Material properties of the aluminum MMCs, like modulus of elasticity, tangent modulus, initial yield stress, etc. were provided by Meijer and Long [18, 19]. Muller determined Maximum tensile stress to be 245 MPa of silicon carbide reinforcements [20].

2.3. MMC microstructures

Li et al. [21] carried out comparison for microstructures of aluminum A359 alloy with A359/SiC composite. It was found SiC particles huddled along the eutectic phase of the matrix. Hardness of the matrix material found very similar to the unreinforced parent alloy by vickers micro hardness measurements. Kannan and Kishawy [22] reported the micro hardness of aluminum metal matrix composites varied inversely with the volume fraction and fineness of the

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

reinforced particles. Rate-dependent properties of the matrix can be considered to be same as that of the unreinforced alloy for analytical modeling purpose.

Table 1. Literature review

Author's Name	Publication year	Workpiece Material	Cutting Tool	Cutting Parameters	Remark
A. Schubert and A. Nestler	2011	AA2124 with 25 % SiC	CVD diamond tipped indexable inserts	tool geometry	An increasing flank wear land width of the inserts led to a reduction of the surface imperfections.
P. Jayaraman and L. Mahesh kumar	2014	AA 6063 T6	uncoated carbide insert	cutting speed, feed rate and depth of cut	feed rate, depth of cut are prominent factors
Puneet Bansal and Lokesh Upadhyay	2016	Aluminum based MMC with 2%, 4% and 6% of alumina	uncoated carbide tool and coated tool	speed, feed rate, depth of cut and percentage of alumina inclusion	Hardness and tensile strength increases with the reinforcement ratio. Surface Roughness increase with the process variables except the speed, speed made adverse effect on surface roughness. MRR increases with the process parameters except the concentration of reinforced particles due the presence of hard ceramic particles
Andreas Nestler and Andreas Schubert	2016	AA2124 with 25 % volume proportion of SiC	polycrystalline diamond tools (PCD) alumina	ultrasonic vibration assistance cutting	Ultrasonic vibration assistance in the radial direction or in the cutting direction respectively leads to stronger Compressive residual stresses in the surface layer, which increases the fatigue strength of the components.
P. Suresh K. Marimuthu S. Ranganathan, T. Rajmohan	2014	Al-SiC-Gr hybrid composites	PCD and cemented carbide	mass fraction of SiC-Gr particles	hybrid composite provides better machinability when compared with composites

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

2.4. MMC strain hardening

Li et al. [23–25] reported high strain rate and quasi static properties under compression and tension of the Al/SiC composites as well as related stress-strain curves and tensile failure strains were reported. It was found that at large strains, both the reinforced matrix and the unreinforced composite show similar degree of strain hardening [26–28]. It was reported that particle reinforcements increase the strain rate sensitivity of the composite depending on the volume fraction, shape and aspect ratio of the reinforced particles [29]. Though, particle fracture under compression slows down strain hardening of the composite [25].

III. MACHINING CHARACTERISTICS

3.1. Material removal

Mechanism of Chip formation in metal matrix composites look like, the behavior of monolithic materials [31]. Joshi et al. [32] highlighted that the most efficient and economical ways of studying the machining characteristics of any material is to study its chip formation details. It was stated that as the volume fraction of the reinforcement particles increases, the number of circles that the chips form before breaking decreases also explained the observation based on decreasing strain at failure of the chip curls. Hence, number of chip curls is directly related to material strain at failure. Ductility of the composite reduces as the increased volume fraction of the hard reinforcements reduces, supporting chip breakage. Tool rake angle affect the chips curl in case of the unreinforced aluminum alloy however composite chip curls remain unaffected. Fundamentally, chip curling depends on the ratio of plastic contact length to total contact length between the chip and the tool face [33]. With increase in this ratio Flatness also increases. Therefore, as the rake angle decreases, chips turn out flatter (chips having greater diameter). At lower cutting speeds, shear strength of the alloy remains high, enabling chip breakage at smaller lengths. But, the same does not happen in case of composites as their low ductility produces much smaller chips. However, it was observed that chip morphology of composites depend on the volume fraction of reinforcements. The chips showed a tendency to stick to the tool face, restricting their movement for lower volume fractions, resulting in longer chips of larger diameters. Joshi et al. [32] have worked on a combined chip breaking criterion that is based on two conditions given by Nakayama [34] and Zhang [35]. Chip breaks when its strain reaches a certain limit, while the latter expressed this limit of strain on chip based on mechanical properties and chip breaker geometry. Comparison with obtained experimental results shows similarity with the model given by Nakayama [34]. Gallab and Sklad [1] also found continuous chips being formed at lower feed rates, which are difficult and hazardous in handling. Lin et al. [30] observed that cutting with sharp tool resulted in the formation of long, helical chips. As the tool became blunt, chips turned to short, helical shapes. It was explained by the researchers as due to lowered ductility of aluminum matrix due to chip breaking action by the built up edges developed on the progressively blunt tool nose.

3.2. Surface roughness

Gradually increased with cutting distance at lower cutting speeds (50 m/min) with PCBN tools machining Al-SiC MMCs, surface roughness (Ra) [9]. This was due to the supremacy of adhesion in high speed cutting. The hard work material diffused to the tool surface and then abraded against the work surface itself, at high cutting speeds. Later, it detached back from the tool to the machined surface and thus induced a many of surface defects such as debris, grooves etc. with increasing Ra value. Use of coolant somewhat controlled the diffusion effect, and helped improve surface quality. Notch wear on the tool translated into replication of the ridges on the machined surface also observed at lower speeds, imparting higher surface roughness. Much better surface quality to the machined surface was imparted due to use of tools with higher notch wear resistance due to higher abrasion hardness. Lin et al. [37] reported that the surface finish improved with increasing cutting speeds at constant feed rate. Better surface finish was obtained with a slightly worn tool due to stabilization of the nose radius. And at constant speeds, with rising feed rates surface finish deteriorated. Similar results were obtained about inverse relationship of surface finish with feed while machining A356/SiC (20p) MMCs by Venkatesh et al. [39]. During turning of LM25 Al/SiC MMC, Arokiadass et al. [40]

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

observed feed to be the most significant parameter affecting surface roughness, followed by spindle speed and weight percentage of particle reinforcement. Muthukrishnan and Davin [41] observed that in turning of Al/SiC (20p) MMC with coarse grade PCD insert, feed rate has maximum influence on surface roughness, followed by depth of cut and cutting speed.

IV. CONCLUSION

Many research have been worked for the machining of metal matrix composites. In this paper a brief overview is provided related research, focusing on turning mechanisms. Metal matrix composites are capable to shape the technological advancements, especially in the auto and aerospace industries. There is increasing trend for MMCs reinforced with nano particles like carbon nano tubes, graphene, nano-SiC. Many attempts are directed toward investigation of hybrid composites, composed of multiple matrix and reinforcement materials.

ACKNOWLEDGMENT

I have taken efforts in this paper. However, it would not have been possible without the kind support and help of many individuals. I would like to extend my sincere thanks to all of them. I am highly indebted to Prof. D. S. Khedekar for their guidance and constant supervision as well as for providing necessary information regarding the paper. I would also like to express my deep gratitude to the Dr. M. S. Kadam for timely support and motivation for this work.

REFERENCES

- [1] El-Gallab M, Sklad M. Machining of Al/SiC particulate metal–matrix composites, Part I: Tool performance. *J Mater Process Technol* 1998;83:151–8.
- [2] Hooper RM, Henshall JL, Klopfer A. The wear of polycrystalline diamond tools used in the cutting of metal matrix composites. *Int J Refract Metals Hard Mater* 1999;17:103–9.
- [3] Chambers AR. The machinability of light alloy MMCs. *Composites A* 1996;27A:143–7.
- [4] Schwartz MM. Composite materials: processing, fabrication, and applications. Englewood Cliffs, NJ: Prentice-Hall; 1997.
- [5] Monaghan J, O'Reilly P. Machinability of aluminumalloy:silicon carbide metal matrix composite. *Process Adv Mater* 1992;2:37–46.
- [6] Hung NP, Zhong CH. Cumulative tool wear in machining metal matrix composites. Part II: Machinability. *J Mater Process Technol* 1996;58:114–20.
- [7] Tomac N, Tonnessen K. Machinability of particulate aluminium matrix composites. *Ann CIRP* 1992;41:55–8.
- [8] Weinert K, Biermann D. Turning of fiber and particle reinforced aluminium. In: *Proceedings of the international conference on machining of advanced materials*. 1993. p. 437–53.
- [9] Ding X, Liew WYH, Liu XD. Evaluation of machining performance of MMC with PCBN and PCD tools. *Wear* 2005;259:1225–34.
- [10] Looney LA, Monaghan JM, O'Reilly P, Taplin DMR. The turning of an Al/SiC metal–matrix composite. *J Mater Process Technol* 1992;33:453–68.
- [11] Zhang ZF, Zhang LC, Mai YW. Wear of ceramic particle reinforced metal–matrix composites, Part I: Wear mechanisms. *J Mater Sci* 1995;30:1961–6.
- [12] Zhang ZF, Zhang LC, Mai YW. Modeling steady wear of steel/Al₂O₃-Al particle reinforced composite system. *Wear* 1997;211:147–50.
- [13] Zhang ZF, Zhang LC, Mai YW. Wear of ceramic particle reinforced metal–matrix composites, Part II: A model of adhesive wear. *J Mater Sci* 1995;30:1967–71.
- [14] Ozben T, Kilickap E, Akir OC. Investigation of mechanical and machinability properties of SiC particle reinforced Al–MMC. *J Mater Process Technol* 2008;198:220–5.
- [15] Pramanik A, Zhang LC, Arsecularatne JA. Prediction of cutting forces in machining of metal matrix composites. *Int J Mach Tools Manuf* 2006;46:1795–803.
- [16] Reddy RR, Sriramakrishna AA. Analysis of orthogonal cutting of aluminium-based composites. *Defence Sci J* 2002;52:375–83.
- [17] Clyne TW, Withers PJ, Davis EA, Ward IM. An introduction to metal matrix composites. Cambridge: Cambridge University Press; 1993.
- [18] Meijer G, Ellyin F, Xia Z. Aspects of residual thermal stress/strain in particle reinforced metal matrix composites. *Composites B* 2000;31:29–37.
- [19] Long SG, Zhou YC. Thermal fatigue of particle reinforced metal–matrix composite induced by laser heating and mechanical load. *Compos Sci Technol* 2005;65:1391–400.
- [20] Muller HK, Nau B. Fluid sealing technology. New York: Marcel Dekker; 1998. p. 294 (Chapter 14).
- [21] Li Y, Ramesh KT, Chin ESC. The mechanical response of an A359/SiCp MMC and the A359 aluminum matrix to dynamic shearing deformations. *Mater Sci Eng A* 2004;382:162–70.
- [22] Kannan S, Kishawy HA. Surface characteristics of machined aluminium metal matrix composites. *Int J Mach Tools Manuf* 2006;46:2017–25.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

- [23] Li Y, Ramesh KT, Chin ESC. The compressive viscoplastic response of an A359/SiCp metal–matrix composite and of the A359 aluminum alloy matrix. *Int J Solids Struct* 2000;37:7547–62.
- [24] Li Y, Ramesh KT, Chin ESC. The mechanical response of an A359/SiCp MMC and the A359 aluminum matrix to dynamic shearing deformations. *Mater SciEng A* 2004;382:162–70.
- [25] Li Y, Ramesh KT, Chin ESC. Viscoplastic deformations and compressive damage in an A359/SiCp metal–matrix composite. *Acta Mater* 2000;48:1563–73.
- [26] Evans AG, Hutchinson JW, McMeeking RM. Stress strain behavior of metal matrix composites with discontinuous reinforcements. *ScrMetallur Mater* 1991;25:3–8.
- [27] Llorca J, Needleman A, Suresh S. An analysis of the effects of matrix void growth on deformation and ductility in metal–matrix composites. *ActaMetallur Mater* 1991;39:2317–35.
- [28] Bao G, Hutchinson JW, McMeeking RM. Particle reinforcement of ductile matrices against plastic flow and creep. *ActaMetallur Mater* 1991;39:1871–82.
- [29] Li Y, Ramesh KT. Influence of particle volume fraction, shape and aspect ratio on the behavior of particle-reinforced metal–matrix composites at high rates of strain. *Acta Mater* 1998;46:5633–46.
- [30] Lin JT, Bhattacharyya D, Lane C. Case study-machinability of a silicon carbide reinforced aluminium metal matrix composite. *Wear* 1995;181–183:883–8.
- [31] Hung NP, Yeo SH, Lee KK, Ng KJ. Chip formation in machining particle-reinforced metal matrix composites. *Mater Manuf Processes* 1998;13:85–100.
- [32] Joshi SS, Ramakrishnan N, Ramakrishnan P. Analysis of chip breaking during orthogonal machining of Al/SiCp composites. *J Mater Process Technol* 1999;88:90–6.
- [33] Rabinowicz E. *Friction and wear of material*. USA: John Wiley; 1965.
- [34] Nakayama K. A study on the chip breaker. *Bull JSME* 1962;5:142–50.
- [35] Zang YZ, Peklenik J. Chip curl, breaking and chip control of difficult-to-cut materials. *Ann CIRP* 1980;29:79–83.
- [36] Davim JP. Application of Merchant theory in machining particulate metal matrix composites. *Mater Des* 2007;28:2684–7.
- [37] Lin JT, Bhattacharyya D, Ferguson WG. Chip formation in the machining of SiC-particle-reinforced aluminum–matrix composites. *Compos SciTechnol* 1998;58:285–91.
- [38] Karthikeyan R, Ganesan G, Nagarazan RS, Pai BC. A critical study on machining of Al/SiC composites. *Mater Manuf Processes* 2001;16:47–60.
- [39] Venkatesh R, Hariharan AM, Muthukrishnan N. Machinability studies of Al/SiC/(20p) MMC by using PCD insert (1300 grade). In: *Proceedings of the world congress on engineering*. 2009. p. II.
- [40] Arokiadass R, Palaniradja K, Alagumoorthi N. Predictive modeling of surface roughness in end milling of Al/SiCp metal matrix composite. *Arch ApplSci Res* 2011;3:228–36.
- [41] Muthukrishnan N, Davim JP. Optimization of machining parameters of Al/SiC-MMC with ANOVA and ANN analysis. *J Mater Process Technol* 2009;209:225–32.
- [42] A. Schubert and A. Nestler “Enhancement of Surface Integrity in Turning of ParticleReinforced Aluminium Matrix Composites by Tool Design” *Procedia Engineering* 19 (2011) 300 – 305
- [43] P. Jayaraman, L. Mahesh kumar “Multi-response Optimization of Machining Parameters of TurningAA6063 T6 Aluminium Alloy using Grey Relational Analysis inTaguchi Method” *Procedia Engineering* 97 (2014) 197 – 204
- [44] Puneet Bansal andLokeshUpadhyay “Effect of Turning Parameters on Tool Wear, Surface Roughness andMetal Removal Rate of Alumina Reinforced Aluminum Composite” *Procedia Technology* 23 (2016) 304 – 310
- [45] Andreas Nestler, Andreas Schubert “Surface Properties in Ultrasonic Vibration Assisted Turning ofParticle Reinforced Aluminium Matrix Composites” *Procedia CIRP* 13 (2014) 125 – 130
- [46] P. SURESH, K. MARIMUTHU, S. RANGANATHAN, T. RAJMOHAN “Optimization of machining parameters in turning of Al-SiC-Gr hybrid metal matrix composites using grey-fuzzy algorithm” *Transactions of Nonferrous Metals Society of China* Volume 24, Issue 9, September 2014, Pages 2805–2814