

A Review on Turning of Metal Matrix Composites

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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.

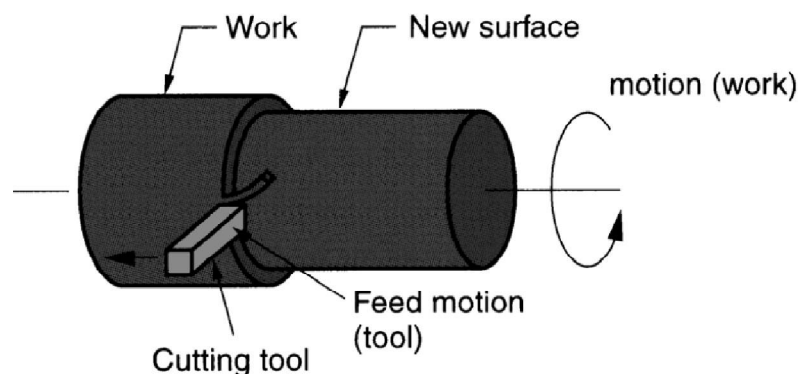


Figure 1. Turning process

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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

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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

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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]

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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.

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