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Review Article

Mechanisms in turning of metal matrix composites: a review

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ABSTRACT

Metal matrix composites have evoked a keen interest from the automobile and aerospace sectors owing to their attractive mechanical properties and applications. Over the past two decades, researchers have unearthed many secrets pertaining to these advanced materials. This paper briefly reviews the research revelations of the mechanisms that make these materials so superior. Turning of metal matrix composites is focused in particular. Mechanisms such as particle fracture, particle pullout, debonding, dislocation phenomena, thermal softening, wear modes, surface generation, cutting forces, chip formation, strains and stresses are addressed. Discussions on related phenomena such as effects of tool coatings, adhesion, friction, microstructures and strain hardening are also presented.

Ravi Sekhar completed his B.Tech. Production Engineering in 2006 and M.Tech. CAD/CAM in 2012, both from Bharatividyapeeth's College of Engineering, Pune, India. He has had 2 years of industrial experience as senior service executive at Head Office, Appliances Division, Godrej and Boyce, Mumbai. He coordinated a multitude of institutional air-conditioner installation projects for national banks like the ICICI, PNB, PSB and Apollo Pharmacy, among others. He has 4 years of teaching experience, and is currently working as assistant professor, Mechanical Engineering Department, Symbiosis Institute of Technology, Symbiosis International University, Pune, India. He is pursuing PhD under the guidance of Dr. T.P. Singh, Director, Symbiosis Institute of Technology. He has published 10 papers in national and international journals and conferences. He is also guiding a number of M.Tech. students.

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1. Introduction

Metal matrix composites (MMCs) are the new age materials that are being preferred by the automotive and aerospace industries for their enhanced properties. These materials exhibit higher strength to weight ratio, hardness, stiffness, wear resistance etc. as compared to conventional metals and alloys. However, these very properties make them difficult to machine. Hence, numerous investigators have dedicated themselves to unraveling various aspects of machining these composites.

There is extensive literature available that records the precious work and contributions in this area by researchers throughout the world. In fact, the available literature is so incredible that the authors of the present work have restricted themselves to a brief discussion of turning mechanisms alone. Some of these mechanisms are very basic, like cutting forces, surface morphology, chip formation. Others are more intricate like particle pullout, particle fracture, debonding, micromechanics.

The purpose of this paper is to provide a brief overview focusing only on mechanisms in turning of MMCs. Topics like preparation, characterization, optimization, simulations have been left out. Of course, ample pointers have been included regarding MMC properties and related tool properties as well. Later, effect of mechanisms like friction, effect of coatings, built up edges (BUE), thermal softening etc. have been discussed. Tool wear has also received due attention, in sections dedicated to abrasion, flank, notch and crater wears. The paper then shifts to advanced mechanisms like tool–particle interactions, debonding, particle fracture. Sections on surface roughness, cutting forces and chip morphology also follow, to clearly understand the peculiar behaviors of the MMCs in turning. Primary results obtained by researchers have been furnished all along, and further details can be obtained from the respective papers.

2. Tool and MMC properties

2.1. Tool selection

In machining metal matrix composites, tool selection is of primary importance. Gallab and Sklad [1] have pointed out the superiority of PCD tools over Al_2O_3/TiC tools owing to their higher hardness and thermal conductivity, which helped heat flow away from the cutting zone. Similar results have been arrived at by other researchers [2–4], where excellent chemical affinity of the MMC with the PCD is also pointed out. In fact, Monaghan et al. [5] ranked various tool materials in the order of decreasing tool wear. Hung [6] found 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 Al_2O_3 coated tools. They confirmed superior performance of CVD tools over the others. Weinert and Biermann [8] advocated PCD and CVD inserts in machining MMCs owing to their low tool wear rates. Regarding hardness, thermal and fracture properties, PCBN tools also fare well against ceramic and cemented carbides, in machining MMCs. Binders also helped improve fracture resistance of tools [9]. Looney et al. [10] reported that cubic boron nitride inserts provided the best overall machining performance in machining Al/SiC MMCs.

2.2. MMC physical properties

For investigation of MMC properties, Zhang et al. [11] developed quantitative models for steady sliding [12] and adhesive wear [13] in wear experiment of a steel disk sliding against metal matrix composite pins. They concluded that increase in particle size was more fruitful than incrementing volume fraction in delaying wear intensification from mild to adhesive modes. Ozben et al. [14] reported that greater SiCp reinforcement directly resulted in higher tool wear. Pramanik et al. [15] discovered a correlation between cutting velocity and the strength of the composite material. For example, only 0.25% of the MMC strength reduced up to a cutting velocity of 50 m/min. Similarly, some studies reported machining temperatures at specified volume fractions, speeds, feeds and depths of cut [16]. Others also determined the extent of change in MMC material properties as per cutting temperatures [17]. Material properties of the aluminum MMCs, like the initial yield stress, modulus of elasticity, tangent modulus etc. were provided by Meijer and Long [18,19]. Maximum tensile stress of silicon carbide reinforcements was determined to be 245 MPa by Muller [20].

2.3. MMC microstructures

Li et al. [21] compared microstructures of aluminum A359 alloy with those of A359/SiC composite. They found SiC particles huddled along the eutectic phase of the matrix. Vickers micro hardness measurements showed that the hardness of the matrix material is very similar to the unreinforced parent alloy (Figs. 1 and 2). According to Kannan and Kishawy [22], the micro hardness of aluminum metal matrix composites varied inversely with the volume fraction and fineness of the reinforced particles. This means that for the purpose of analytical modeling, rate-dependent properties of the matrix can be considered to be same as that of the unreinforced alloy.

2.4. MMC strain hardening

Li et al. [23–25] have determined high strain rate and quasi static properties of the Al/SiC composites in compression and tension. Related stress-strain curves, and tensile failure strains have also been reported. Researchers have pointed out that at reasonably large strains, both the unreinforced matrix and the reinforced composite show similar degree of strain hardening [26–28]. But, the particle reinforcements increase the strain rate sensitivity of the composite depending on the volume fraction, shape and aspect ratio of the reinforced par-