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Effect of reinforcement on the cutting forces while machining metal matrix composites–An experimental approach

Ch. Shoba [a,*], N. Ramanaiah [b], D. Nageswara Rao [c]

[a] Department of Industrial Engineering, GITAM University, Visakhapatnam, 530045, India
[b] Department of Mechanical Engineering, Andhra University, Visakhapatnam, India
[c] Centurion University, Odisha, India

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Hybrid metal matrix composites are of great interest for researchers in recent years, because of their attractive superior properties over traditional materials and single reinforced composites. The machinabilty of hybrid composites becomes vital for manufacturing industries. The need to study the influence of process parameters on the cutting forces in turning such hybrid composite under dry environment is essentially required. In the present study, the influence of machining parameters, e.g. cutting speed, feed and depth of cut on the cutting force components, namely feed force (F_f), cutting force (F_c), and radial force (F_d) has been investigated. Investigations were performed on 0, 2, 4, 6 and 8 wt% Silicon carbide (SiC) and rice husk ash (RHA) reinforced composite specimens. A comparison was made between the reinforced and unreinforced composites. The results proved that all the cutting force components decrease with the increase in the weight percentage of the reinforcement: this was probably due to the dislocation densities generated from the thermal mismatch between the reinforcement and the matrix. Experimental evidence also showed that built-up edge (BUE) is formed during machining of low percentage reinforced composites at high speed and high depth of cut. The formation of BUE was captured by SEM, therefore confirming the result. The decrease of cutting force components with lower cutting speed and higher feed and depth of cut was also highlighted. The related mechanisms are explained and presented.

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1. Introduction

Metal matrix composites (MMCs) offer high strength to weight ratio, high stiffness and good wear and corrosion resistance, all factors which make them an attractive option in replacing conventional materials for many engineering applications. Now a day, composites with more than one reinforcement usually referred as hybrid composites are finding increased applications because of improved mechanical properties and hence are better substitutes for single reinforced composites [1]. In the present day scenario, machining of MMCs involves a significant challenge to the industries. Several problems have been encountered during high speed machining of MMCs and its effect on cutting forces, progression of tool wear and surface integrity of the machined product is of great interest. As discussed by Loovey et al. [2] MMCs are difficult to machine due to the presence of hard abrasive ceramic reinforcing medium set within a more ductile matrix material. Machining MMCs is difficult as the ceramic reinforcements build them stronger and stiffer than the base matrix. Hoecheng et al. [3] have studied the effect of speed, feed, depth of cut, rake angle and cutting fluid on the chip formation and the forces generated during machining of MMCs. An increase in the volume fraction of the reinforcements hinders chip formation by larger plastic shear and assists successive fracture of chips. The decrease in cutting forces with negative rake angle results from a large clearance angle, which helps in the reduction of friction and increases tool life. Pramanik et al. [4] studied the cutting forces while machining metal matrix composites. According to Pramanik the force generation mechanism was considered to be due to three factors: (a) the chip formation force, (b) the ploughing force, and (c) the particle fracture force. The experimental results revealed that the force due to chip formation is much higher than those due to ploughing and particle fracture.

* Corresponding author. Tel.: +91 9985032287.
E-mail address: shobachintada@gmail.com (Ch. Shoba).
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Table 1
Chemical composition of A356.2 Al Alloy matrix.

Si	Fe	Cu	Mn	Mg	Zn	Ni	Ti
6.5–7.5	0.15	0.03	0.10	0.4	0.07	0.05	0.1

Kannan et al. [5] investigated and provided information on the deformation behavior of particulate reinforced composites, which can improve the performance and accuracy of machining MMCs. His study revealed that the machining forces are correlated to the plastic deformation characterization of the matrix material. Anandakrishnan et al. [6] studied the machinability of in situ Al-6061–TiB_2 metal matrix composite. The effect of machinability parameters such as cutting speed, feed rate, and depth of cut on flank wear, cutting force and surface roughness were analyzed during turning operations. Their results confirmed that the higher TiB_2 reinforcement ratio produces higher tool wear, surface roughness and minimizes the cutting forces, while a higher feed rate increases the flank wear, cutting force and surface roughness. Sikder et al. [7] studied and investigated the effect of particle size on the machining forces. Shear force, ploughing force and particle fracture force are considered to estimate the cutting forces. Chip-tool interface friction in the machining of Al/SiCp composites has been considered which involves two body abrasion and three bodies rolling on the work of Uday et al. [8]. In his study, chip–tool interface friction in the machining of Al/SiCp composites has been considered to involve two-body abrasion and three-body rolling caused due to presence of reinforcements in composites. The model evaluates resulting coefficient of friction to predict the cutting forces during machining of Al/SiCp composites. His work suggested that 40% of the reinforced particles contribute to the abrasion at the chip–tool interface. Suresh et al. [9] has attempted to find the optimal level of machining parameters for multi performance characteristics in turning of Al/SiC/Gr hybrid composites using a grey–fuzzy algorithm. They reported that 10% reinforced SiC and Gr reinforced hybrid composites provide better machinability when compared with 5% and 7.5% of SiC–Gr composites. Cutting speed, depth of cut and weight percentage of SiCp are the selected parameters while turning aluminum metal matrix composites in the work of Joardar et al. [10]. The authors reported that the cutting speed is the most significant factor influencing the response variables. Kishawy et al. [11] presented an analytical model for predicting tool flank wear progression during turning of particulate reinforced MMCs. A methodology was proposed for analytically predicting the wear progression as a function of tool/workpiece properties and cutting parameters. According to their model the wear mechanisms that were identified during cutting MMCs were two body and three body abrasions. The effect of work piece reinforcing percentage on the machinability of Al–SiC metal matrix composites has been studied by Muthukrishnan and Paulo Davim [12]. The result showed that maximum tool flank wears was observed while machining 20% of the SiC reinforcing MMC when compared with 10% of the SiC reinforcing MMC.

Rice husk ash is one of the most inexpensive and available in large quantities thorough out the world. The presence of high silica content (above 90%) in the RHA, makes the possible use of it as a reinforcement of widespread applications. The objective of the present paper is to study the machinability of the Al/RHA/SiC hybrid composites at different cutting conditions like cutting speed, feed and depth of cut.

Table 3
Cutting conditions.

Cutting tool	Cemented carbide
Specification	SNMG 120408
Tool holder	CTANR 2525-M16
Tool geometry	0-10-6-6-8-75-1 mm (ORS)
Cutting speed (m/min)	40,60,100,150,200
Feed (mm/rev)	0.14, 0.16, 0.2, 0.25, 0.3
Depth of cut (mm)	0.5, 0.75, 1.0, 1.5, 2.0
Cutting condition	Dry

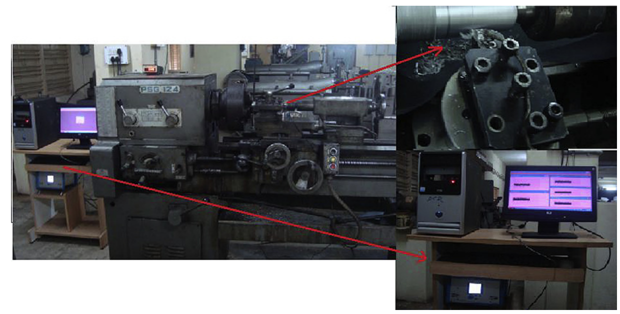

Fig. 1. Lathe machine with Kistler dynamometer.

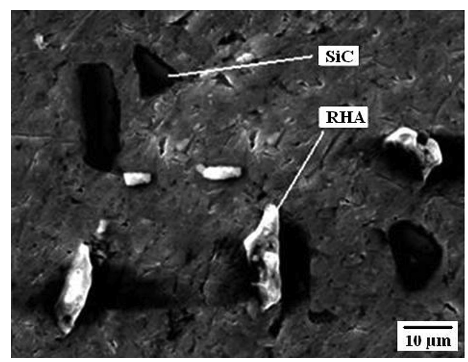

Fig. 2. Scanning electron micrograph of Al/6% SiC/6%RHA hybrid composite.

2. Experimentation

In the present study, A356.2 aluminum alloy was used as a matrix material. SiC and RHA are used as reinforcing materials with an average size of 35 μm and 25 μm respectively. The rice husk ash particulates have assorted sizes and shapes. However, most of the particulates have hull like structure. The chemical composition of A356.2 and RHA are presented in Tables 1 and 2. The composites were fabricated by the stir casting technique and the details are presented in the earlier works [13]. Composites made up of aluminium reinforced with 2, 4, 6, and 8 by weight% of SiC and RHA in equal proportion are fabricated in the form of cylindrical rods of 35 mm diameter and 350 mm long. JSM 6610LV scanning electron microscope (SEM) equipped with energy dispersive X-ray analyzer

Table 2
Chemical composition of RHA.

Constituent	Silica	Graphite	Calcium oxide	Magnesium oxide	Potassium oxide	Ferric oxide	L.O.I
%	90.23	4.77	1.58	0.53	0.39	0.21	2.29

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