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

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ABSTRACT

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.

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.

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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

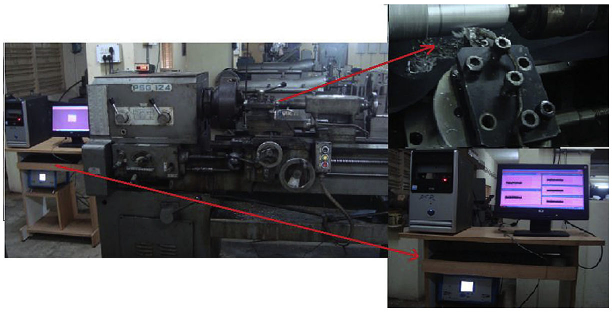

Fig. 1. Lathe machine with Kistler dynamometer.

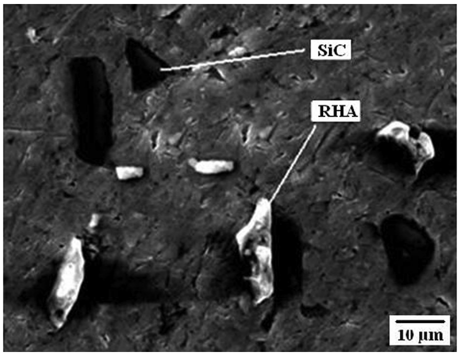

Fig. 2. Scanning electron micrograph of Al/6% SiC/6%RHA hybrid composite.

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

(EDX) is used to study the microstructure of the hybrid composite and the tool wear. Optical microscope (OLYMPUS) was used to study the porosity in the hybrid composites. The specimens were turned on a lathe machine using cemented carbide insert with

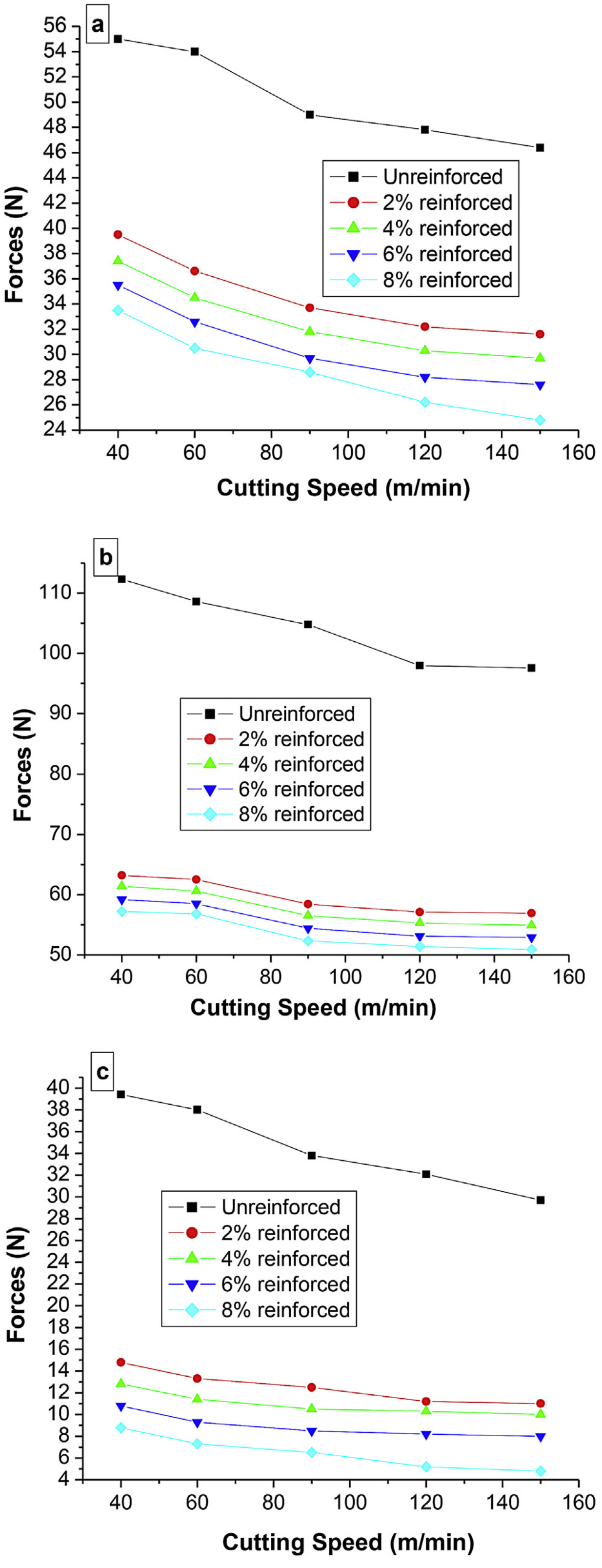

Fig. 3. Variation of forces with cutting speed a) feed force b) cutting force and c) radial force at constant feed 0.14 mm/rev and depth of cut 0.5 mm.

Table 4
Hardness and porosity values of hybrid composites.

S.No.	Weight (%) of reinforcement	Hardness (BHN)	Porosity (%)
1	0.0	68	1.01
2	2.0	74	2.11
3	4.0	83	2.53
4	6.0	96	2.96
5	8.0	104	3.34

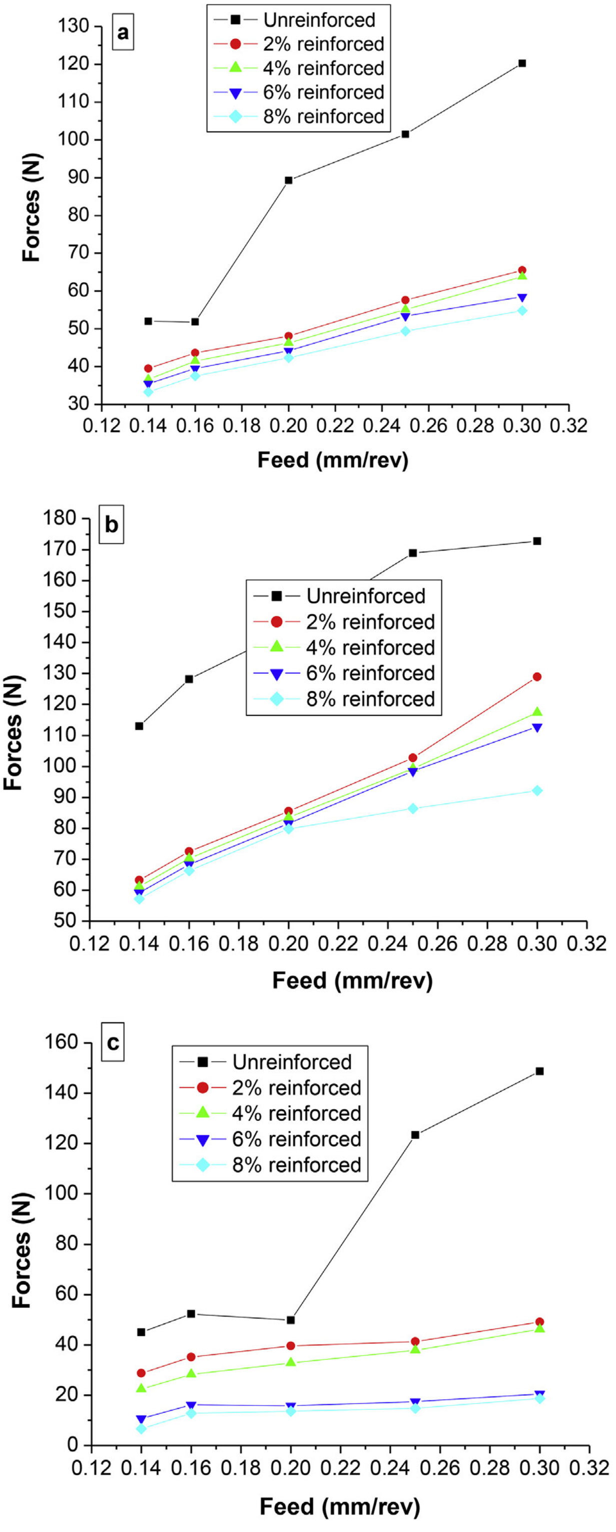

Fig. 4. Variation of forces with feed a) feed force b) cutting force and c) radial force at constant cutting speed 150 m/min and depth of cut 0.5 mm

cutting conditions given in Table 3. For each test condition, feed force (F_f), cutting force (F_c), and radial force (F_d) are measured using a dynamometer (Kistler type 9272). The set-up was shown in Fig. 1. Dynamometer is based on the principle that force can be measured through its action on a system offering a finite resistance and the technique is based on the principal of the transducer. The measurement system involves a transducer, a signal convertor and an indicator. For each trail cutting was performed for 10 Sec.

3. Results and discussions

Fig. 2 shows the scanning electron micrograph of the 6% reinforced hybrid composites. From the micrograph, a uniform distribution of SiC and RHA particulates has been observed. Fig. 3a–c shows the variation of cutting forces for unreinforced and Al/SiC/RHA hybrid composite with 2, 4, 6 & 8% reinforcement in equal proportion for variable cutting speed, keeping feed (0.14 mm/rev) and depth of cut (0.5 mm) as constant. From the figure it was observed that, all the cutting force components F_f, F_c, and F_d for the unreinforced alloy (A356.2) were found to be more than the reinforced specimens which is explained in the later section. It was also observed that, the cutting force components decreases with the increase in cutting speed and decreases with the increase in the percentage of reinforcement. The decrement in cutting forces was observed with the increase in cutting speed which may be attributed due to thermal softening of the work-piece and this is in good agreement with the works reported by Gallab et al. [14]. The decrease in the force components with the increase in the percentage of reinforcement was probably due to the increase in the hardness of the hybrid composites. As the reinforcement increases hardness increases. The hardness of the hybrid composites was measured and presented in earlier works [13]. The corresponding values are presented in Table 4. The addition of hard abrasive particles into the matrix changes the deformation behavior of the soft ductile matrix. As the volume fraction of the reinforcement increases, hardness increases, which results in the chip formation by large plastic shear and which is in good agreement with Hoecheng et al. [3]. Hence the chips formed due to large plastic shear may increase with the increase in the percentage of reinforcement and this could be the possible reason for the decrease in the force components with the increase in reinforcement.

Fig. 4a–c represents the cutting force components at varying feed keeping cutting speed (150 m/min) and depth of cut (0.5 mm) constant for both base material and the hybrid specimens with varying reinforcement. All cutting force components were found to increase with an increase in feed rate and decreases with the increase in the weight percentage of the reinforcement. Feed has the major contribution on the cutting forces rather than the cutting speed and depth of cut from past research. The cutting force components were found to increase with the increase in feed rate, which can be attributed to the increase in the friction between the cutting edge and the work-piece. The decrease in cutting force components with the increase in reinforcement can be ascribed to the increase in porosity. During fabrication of composites porosity is a common phenomenon which cannot be fully avoided but can be minimized. The porosity of the hybrid composites was measured and presented in the prior work [13] and the corresponding values are tabulated in Table 4. Fig. 5 shows the optical micrographs of the pores present in the hybrid composites. From the optical micrographs it was observed that the porosity increases with the increase in the reinforcement, when the tool passes through these pores less force is required to machine the composite and hence a decrease in cutting force components was noticed.

The variation of forces with varying depth of cut keeping cutting speed (150 m/min) and feed (0.14 mm/rev) constant are represented in Fig. 6a–c. It was observed that the depth of cut has major effect when compared to feed and cutting speed. From the plots it was observed that the cutting force components increase with the depth of cut and found to decrease with the increase in the reinforcement. As the depth of cut increases, the contact area between the cutting edge and the work-piece increases, which eventually increases the cutting force components. The decrease in cutting

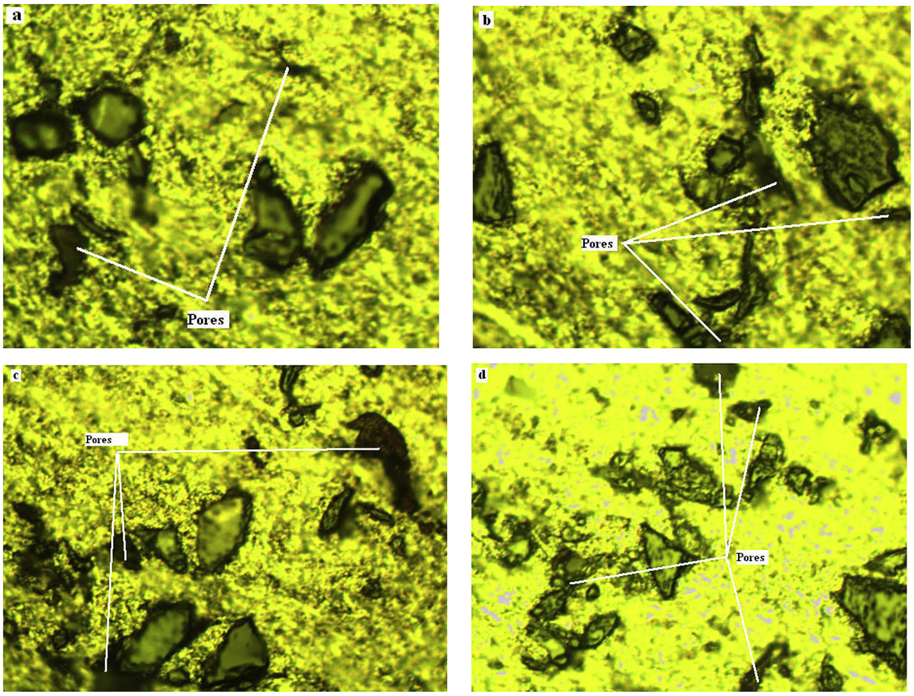

Fig. 5. Optical micrograph showing porosity of hybrid composites a) 2% b) 4% c) 6% and d) 8% at 20X.

forces with the increase in the reinforcement can be ascribed to the formation of a tiny projection on the surface of the cutting tool usually referred as built up edge (BUE), at lower reinforcement (2%). For lower volume fractions of reinforcements the chips tend to stick to the tool face, which may generate BUE and hence more cutting forces are noticed. Fig. 7 shows the SEM micrograph of the formation of BUE for a cutting speed of 150 m/min, feed 0.14 mm/rev and depth of cut of 2 mm.

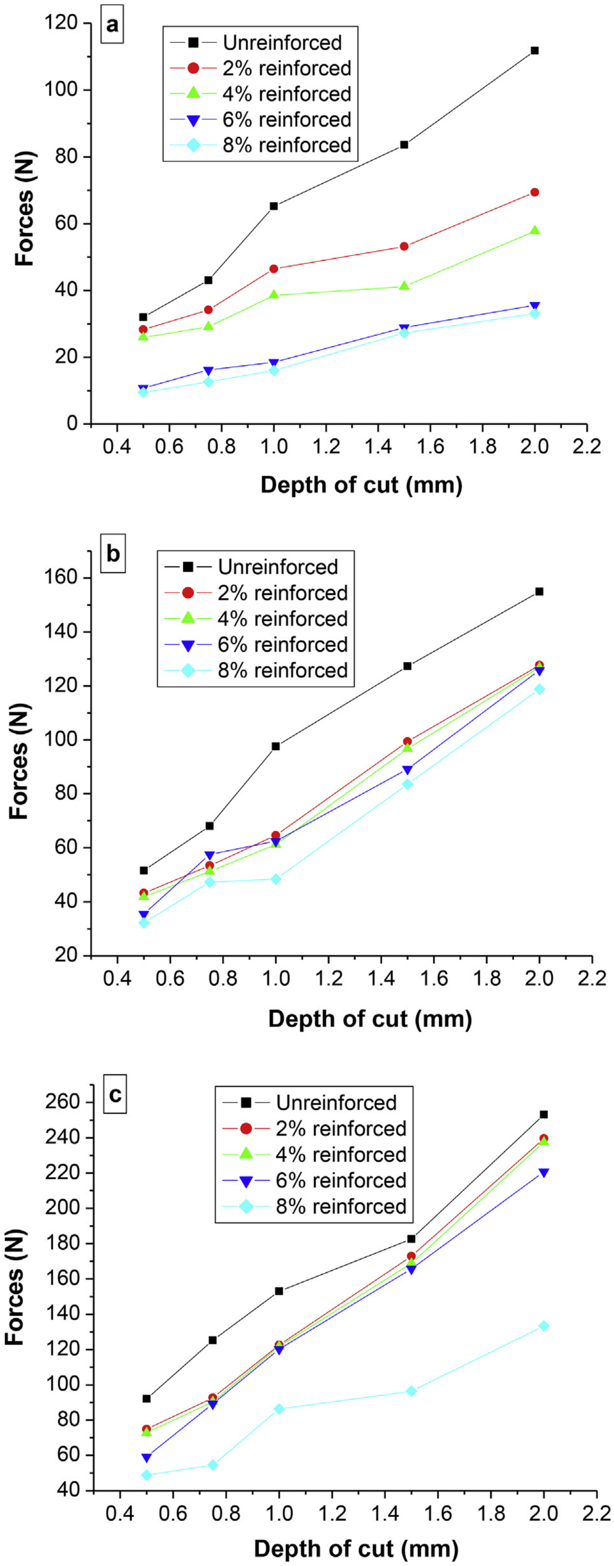

Fig. 6. Variation of forces with depth of cut a) feed force b) cutting force and c) radial force at constant cutting speed 150 m/min and depth of cut 0.5 mm.

From all the above cases of machining, it was observed that the cutting force components were found higher for unreinforced alloy than the composites. This can be attributed to the following reason:

Metal matrix composites are characterized by a large difference in the thermal expansion coefficient (CTE) of the matrix and the reinforcements. The CTE values of A356.2 alloy, RHA and SiC particulates are 21.4 × 10^{-6}/°C, 10.1 × 10^{-6}/°C and 4.3 × 10^{-6}/°C respectively. As the composite fabrication involves a large temperature gradient, the dislocation density generated can be quite significant at the interface and can be predicted using the model of Taya and Arsenault [15] based on prismatic punching of dislocations at a ceramic particulate. The dislocation density ρ at the interface can be predicted using the Equation (1).

$$\rho = \frac{B\varepsilon V_r}{bd(1-V_r)} \tag{1}$$

Where, B is a geometric constant, ε is the thermal mismatch strain (the product of temperature change ΔT, during solidification of MMCs and CTE difference, Δα, between reinforcement and matrix), V_r is the volume fraction of the reinforcement, b is the burgers vector, d is the average grain diameter of reinforcements.

The dislocation density generated at the interface plays a vital role on the cutting forces when machining the composite. The decrease in force components in all the cases, for the composite was probably due to the dislocation densities generated which results from the CTE mismatch between the reinforcement and the matrix. When the tool passes through these dislocations minimum force is required to machine the composite which might be the possible reason for the decrease in forces for the reinforced specimens when compared to the unreinforced alloy.

4. Conclusions

An attempt was made to study the cutting force components when machining hybrid composites using dynamometer. This practical research will provide essential guidelines for the researchers in the area of composites. The cutting force components are evaluated at different machining conditions for both reinforced and unreinforced specimens. From the study, the following conclusions are drawn.

- All the cutting force components decrease with cutting speed due to thermal softening of the work-piece. The cutting force components decrease with an increase in weight percentage and this is due to the hard reinforced abrasive SiC and RHA particles embedded into the matrix.

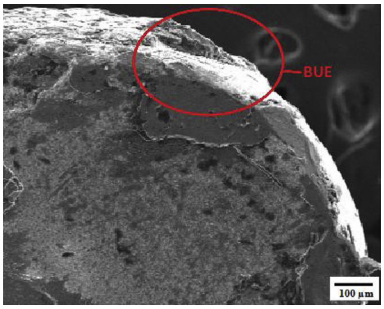

Fig. 7. SEM micrograph showing BUE.

- Friction plays a vital role which affects the cutting forces. The cutting force components increases with feed due to the increase in the friction between the cutting edge and the work-piece. Porosity is observed to be the dominant factor for the reduction of cutting force components with reinforcement for variable feed rate.
- The cutting force components increases with the depth of cut and this is due to the increase in the contact area between the cutting edge and the work-piece. Built up edge generated at lower volume fractions is the primary reason for the increase in cutting forces. Hence it is understood that the cutting force components decrease with the increase in volume fraction for varying depth of cut. The formation of BUE for the composite with low volume fraction was observed due to the chips that tend to adhere to the cutting tool.
- The cutting force components are much lower for hybrid composites than unreinforced alloy due to the dislocation densities generated from the thermal mismatch between the reinforcement and the matrix.

References

[1] D. Siva Prasad, C.H. Shoba, Hybrid composites—a better choice for high wear resistance materials, J. Mater Res. Technol. 3 (2) (2014) 172–178.

[2] L.A. Loovey, J.M. Monaghan, P.O. Reilly, D.M.R. Taplin, The turning of an Al/SiC metal matrix composite, J. Mater. Process. Technol. 33 (1992) 453–468.

[3] H. Hoecheng, S.B. Yen, Yen B.K. Ishihara, Fundamental turning characteristics of tribology favored graphite/aluminium alloy composites, Compos. A 28A (1997) 883–890.

[4] A. Pramanik, L.C.S. Zhang, J.A. Arsecularatne, Prediction of cutting forces in the machining of metal matrix composites, Int. J. Mach. Tools Manuf. 46 (14) (2006) 1795–1803.

[5] S. Kannan, H.A. Kishawy, I. Deiab, Cutting forces and TEM analysis of the generated surface during machining metal matrix composites, J. Mater. Process. Technol. 209 (2009) 2260–2269.

[6] V. Anandakrishnan, A. Mahamanj, Investigations of flank wear, cutting force and surface roughness in machining of Al 6061-TiB_2 in situ metal matrix composites produced by flux assisted synthesis, Int. J. Adv. Manuf. Technology 55 (2011) 65–73.

[7] S. Sikder, H.A. Kishawy, Analytical model for force prediction when machining, metal matrix composites, Int. J. Mech. Sci. 59 (2012) 95–103.

[8] A. Uday Dabade, Dilip Dapkekar, S. Suhas Joshi, Modelling of chip tool interface friction to predict cutting forces in the machining of Al/SiC_P composites, Int. J. Mach. Tool Manuf. 49 (2009) 690–700.

[9] P. Suresh, K. Marimuthu, S. Ranganathan, T. Rajmohan, Optimisation of machining parameters in turning of Al-SiC-Gr hybrid metal matrix composites using grey-fuzzy algorithm, Trans. Non-Ferrous Metals Soc. China 24 (2014) 2805–2814.

[10] H. Joardar, N.S. Das, G. Sutradhar, S. Singh, Application of response surface methodology for determining cutting force model in turning of LM6/SiCp metal matrix composite, Measurement 47 (2014) 452–464.

[11] H.A. Kishawy, S. Kannan, M. Balazinski, Analytical modeling of tool wear progression during turning particulate reinforced metal matrix composites, CIRP Ann. Manuf. Technol. 54 (1) (2005) 55–58.

[12] N. Muthukrishnan, J. Paulo Davim, An investigation of the effect of work piece reinforcing percentage on the machinability of Al-SiC metal matrix composites, J. Mech. Eng. Res. 3 (1) (2011) 15–24.

[13] D. Siva Prasad, Ch Shoba, N. Ramaniah, Investigations on mechanical properties of aluminium hybrid composites, J. Mater Res. Technol. 3 (2014) 79–85.

[14] El-Gallab, M. Sklad, Machining of Al/SiC particulate metal matrix composites, part I: tool performance, J. Mater. Process. Technol. 83 (1998) 151–158.

[15] M. Taya, R.J. Arsenault, Metal Matrix Composites-thermomechanical Behavior, Pergamon publishers, New York, U.S.A, 1989.