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Machinability of Hybrid Metal Matrix Composite - A Review

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Abstract

Aerospace and automotive industries are eager on introducing hybrid metal matrix composites in their components due to their excellent mechanical and physical properties, leading to reduction in the weight of structural components and energy requirement for propelling. Components made by hybrid metal matrix composite (based on Aluminum alloy reinforced with single wall and multi wall carbon nanotubes, Graphene and ceramic particles) required secondary operations to enhance the dimensional tolerance and surface finish. Machining operations generally requires minimum tool wear rate and good surface finish with lowest energy requirement. Hard metal, ceramic and oxide reinforcements in the composite increase the tool wear and machining cost. To improve tool life and increase the metal removal rate significant care is needed for the selection of optimum cutting parameters and cutting conditions. This review focuses on the influence of reinforcement particle's types, shape, size and volume fractions on the machinability issues like the cutting force, tool wear, chip formation and surface roughness. Further, the role of various cutting parameters like cutting speed, feed, depth of cut and tool material, tool geometry and cutting conditions during turning of hybrid metal matrix composites are critically reviewed.

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Keywords: Hybrid Metal Matrix Composite, Machinability, Turning, Cutting parameters

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1. Introduction

Now a day, high product quality and better surface finish draws attention in manufacturing industry. Usage of more than one reinforcement usually denoted as hybrid composites increasing significantly due to its outstanding mechanical and physical properties. Hybrid composites considered as good alternative for single reinforced particle composites [1]. Matrix and reinforcements are in particulate form are called particulate metal matrix composites (PMMC) giving superior manufacturability than the other fabrication methods [2]. However products made by particulate metal matrix composites required some machining operations to attain good dimensional tolerance and surface finish. Turning is the most important machining operation for cutting and finishing operations. Presence of hard abrasive reinforcement particles influences greatly in tool wear and cost associated with machining. Selection of optimum machining parameters is very important to attain high cutting performance in metal matrix composites (MMCs) [3,4]. Machinability generally expressed in factors like cutting forces, angle of friction, tool wear, formation of chip and surface finish. Good machinability consumes less power, low tool wear rate, excellent surface finish etc. Achieve a good assessment of the machinability is a difficult concern due to complexity of the reinforcement mechanisms of the hard ceramic particles [5]. In aerospace and automotive applications aluminum silicon carbide composites are showing great demand because, aluminum possess the advantage of light weight and ceramic reinforcement giving excellent hardness [6,7]. Metal matrix composite reinforced with carbon nanotube (CNT) shows excellent strength and improved elastic modulus than the monolithic materials [8,9].

2. Matrix

Aluminium, magnesium and copper mostly investigated matrix materials due to its high strength to weight ratio. [10]. Aluminium and magnesium have earmarked their slot in the MMCs due to low density and machinability [11]. Elements like silicon, zinc, magnesium, and copper are gifted with adequate solubility which makes them feasible to be used as key alloying elements [12]. Particle size having significant role in the MMCs. Grain refinement can reduce the thermal expansion, hence strength of the matrix increased [8]. Strength of the matrix enhances with decrease in grain size but the overall output not improved significantly. Shape, size and volume fraction of the reinforcement also have an important role in strength of the composite.

3. Hybrid

Hybrid MMCs were formed by reinforcing the base matrix with more than one reinforcements having different properties. Those composites which have a mixture of two or more reinforcement particles are capable of enhance the mechanical properties of the composite [13]. The performance of hybrid composites is a collective effect of the individual constituents in which there is a better balance between the inbuilt advantages and disadvantages. Silicon carbide (SiC), alumina (Al_2O_3), boron carbide (B_4C),tungsten carbide (WC), graphite (Gr), single or multi carbon nanotubes (CNT) and silica (SiO_2) are a few of the reinforcements which are used, but silicon carbide and alumina are typically used compared to other reinforcing materials.

4. Effect of particle shape, size and volume fraction

Presence of hard reinforcement particles affects the machinability of the MMC [1]. Tool wear and requirement of cutting force during the machining of metal matrix composite is extremely dependent on the size and volume fraction of reinforcement particles [4]. Flank wears increases with increase in size and volume fraction of the abrasive particles also it depends on the amount of hard metal or abrasive particles approaching to contact with cutting tool [14]. The influence of particles size on flank wear is shown in Fig.1.Tools wear mostly due to the abrasive mechanism of the hard particles. If the particles are in nanometer scale the tool wear rate is very less and it increases the tool life and machinability.

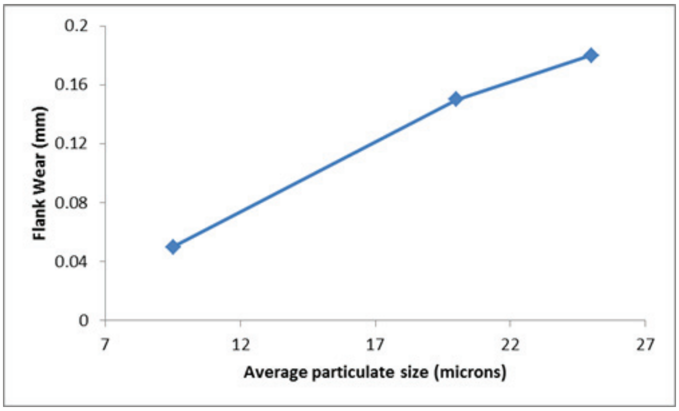


Fig.1.Flank wear during machining of Al 6061/10% Al_2O_3 composite with various particles size [14]

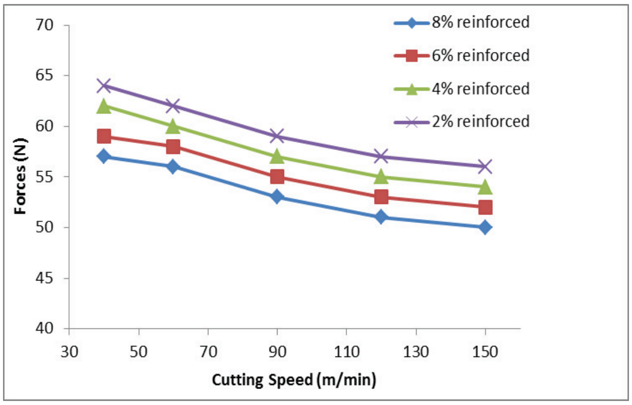


Fig.2.Effect of reinforcement volume fraction on cutting forces for varying cutting speeds [1]

Recent research reveals that reinforcement particles in nanometer scale exhibits better mechanical performance (good wear resistance, yield strength) than the MMC reinforced with micro scale particles. In case of larger particles tool wear is very high and it is reducing the tool life. Fig.2. shows the effect of reinforcement volume fraction on cutting forces with cutting speed.

5. Tool Material

Machining of metal matrix composites with hard reinforcements increases the machining cost, tool wear and premature failure of tool. Tool wear and metal removal rate (MRR) in turning operation depends on several parameters such as cutting speed, feed, depth of cut, work material, work piece hardness and tool angles etc. However during machining cutting speed, feed and depth of cut are the most influencing parameters [4]. Ravinder Kumar and Santram Chauhan [6] recommended polycrystalline diamond (PCD) tools offer higher tool life due to its high hardness and thermal conductivity. They suggested that PCD tools offered the good wear resistance since it can sustain a steady TiC reaction layer on the surface of the tools. This layer controls the wear rate due to the presence of carbon atoms. They investigated the effect of cutting parameters on surface roughness in turning of Al 7075/10 wt. % SiC and 7 wt. % SiC/ 3 wt.% graphite using polycrystalline diamond tool (PCD). The fig.3.shows the influence of depth of cut on cutting force for UCTC and PCD tools during turning of Al 6061-TiC metal matrix composite. Kannan et al. [14] presented cemented carbides and ceramic tools also used to machining metal matrix composites due its lower cost than the PCD tools.

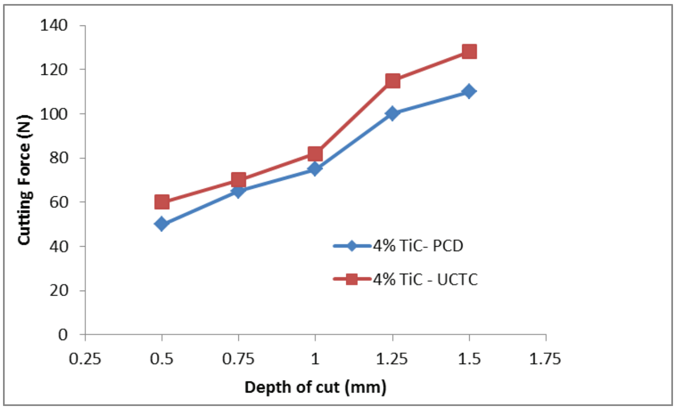


Fig.3.Influence of depth of cut on cutting force for UCTC and PCD tools [7]

6. Cutting Forces

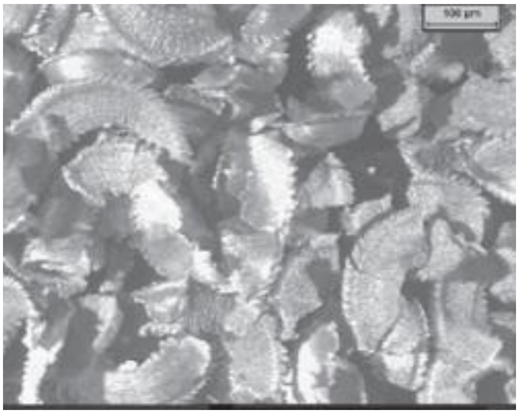
Cutting force mainly depends on the matrix and reinforcements materials structure, interface and properties. Abbas Razavykia et al.[2] have studied the cutting profiles of Mg based metal matrix composite and reported that the profile was not smooth when compared with the pure Mg due to the presence of nano ceramic reinforcement. The author also emphasized the existence of reinforcement particles form the tendency for the tool deflection and increase the cutting force needed for machining. Pramanik et al. [5] indicated that the cutting speed did not affect more during machining of the MMC compares with pure alloy. Requirement of cutting forces needed for the non- reinforced alloy less than that of MMC at the initial stage and it increases with the increase in speed. The cutting forces differences between the MMC and its alloy due to the variations of thermal softening, interaction between tool- particles and work hardening effect. Ch. Shoba et al. [1] reported the mechanism of force generation depends on the factors like force required for ploughing, fracture and chip formation and they presented chip formation consumes more power than the other mechanisms. They also reported that the hybrid composites need lower cutting force than the non-reinforce alloy due to the thermal mismatch among the abrasive reinforcement particles and the matrix materials.

7. Effect of cutting fluid, friction and lubrication

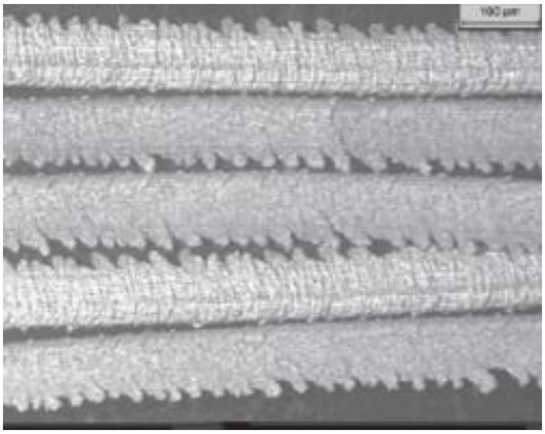
Friction and lubrication act as an important role in machining of metal matrix composite, especially in cutting forces. When the feed rate increases the cutting forces also increases because of development of friction between the cutting edge and work piece. Presence of porosity decreases the force required for the cutting. Ch. Shoba et al. [1] reported that the addition of mica in Al 356/SiC/RHA metal matrix composite reduces the flank wear because of the lubricating properties of mica. During machining a significant amount of energy is transformed into heat due to the friction acting between the work piece and cutting tool and also this heat formation is not desirable for good machining environment. Lubricants and cutting fluids are necessary for almost all machining operation for cooling and lubricating the tool and work piece to improve machinability, dimensional tolerance and quality of the product [6,8,15]. Sujan D et al. [15] absorbed cutting fluid influences in greatly to surface roughness (33.1%) as well as to tool wear (13.7%). Low flow high-velocity (LFHV) method was the very effective flow condition up to a particular level for minimizes surface roughness and rate of tool wear during the machining of MMC. They also reported during machining titanium alloys pneumatic mist jet impinging cooling (PMJIC) is a most effective cooling as well as lubricating method and it reduce the tool wear rate. Modern machining industries are keen on using nano lubricant due to its effectiveness during machining because of the rolling action of the nano particles at tool- work piece interface. The efficiency of the nano lubricant is based on the size, crystallographic arrangement and morphology. However significant consideration also required for selection and usage of these cutting fluids and lubricators due to the environmental and health problems.

8. Chip formation

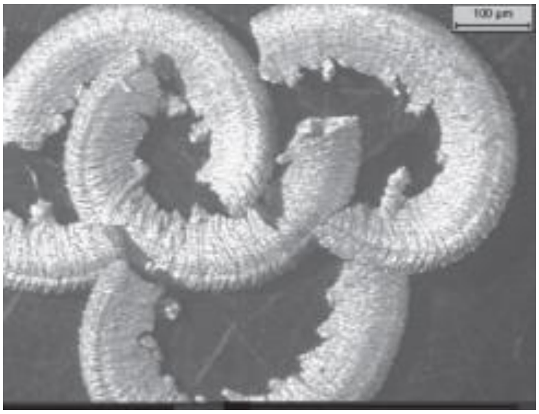
Formation of chip deeply depends on cutting parameters like cutting speed, feed and depth of cut and this is also influencing the tool life [5]. When the cutting speed increases the radius of curvature also increases due its variations of material inertia between the shear planes [15]. Ravinder Kumar and Santram Chauhan [6] reported small amount of built up edge formation at high cutting speed and high at lower cutting speed. Existence of hard reinforcement particles enhances the chip breakability in composites. Fig.4. shows the shape of chips at various feed rates during the machining of Al 7075/10/SiC metal matrix composites. Force required to form the chips in turning depends on the strength of the materials, tool geometry and cutting conditions. A. Pramanik et al. [5] studied Al 6061/20 vol% SiC metal matrix composite at feed level 0.025mm/rev, chips were uneven in shape as well as very short and lengthy chips were formed at increase in feed level. At feed level 0.05 and 0.1mm/rev, lengthy spiral and straight chips were formed correspondingly, However additional rise of feed (0.2 and 0.4mm/rev), entire chips converted into short and C-shape. In plastic deformation zone unequal strain will develop and it will form curl in continuous chips. The formation curl depends on the type of material (ductile of brittle). In brittle material have slight or no indication to curl, but in case of ductile material very long spiral chips will form. Hard reinforcement particles show better chip disposability.



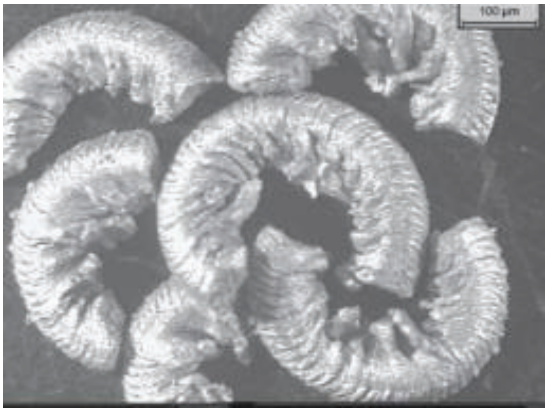
(a) 0.025 mm/rev



(b) 0.1 mm/rev



(c) 0.2 mm/rev



(d) 0.4 mm/rev

Fig..4. Shape of chips at various feed rates during the machining of Al 7075/SiC metal matrix composites [5]

9. Surface Roughness

Surface finish is an important parameter to decide the quality of the product and also very essential factor for machining process[14]. Surface roughness in machining operations mainly depends on the machining parameters like cutting speed, feed, depth of cut and approach angle [8,16,]. Fig.5. shows the effect of cutting speed on the surface roughness of the Al based MMC. Ravinder Kumar and Santram Chauhan [6] studied good surface finish at low feed rate (0.05 mm/rev) and high cutting (170 m/min). Existence of graphite particle into Al metal matrix composite enhances the surface roughness due to the lubricating effect [17]. The relationship between factors like feed rate and cutting speed has also contributing considerable influence on surface roughness of the composite.

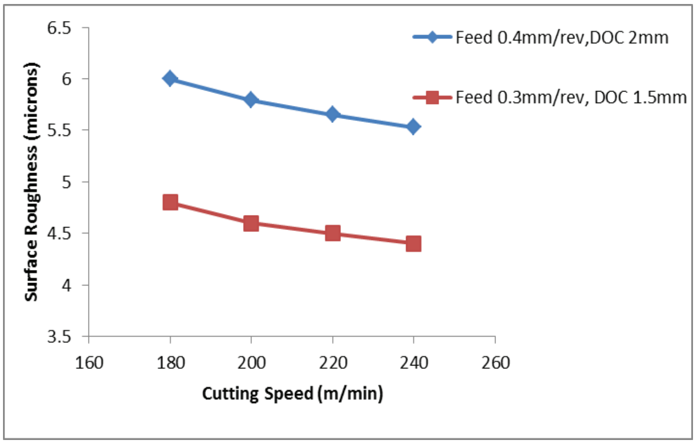


Fig.5. Relationship between cutting speed and surface roughness of the Al MMC

10. Conclusions

The surface roughness mainly depends on the feed rate followed by the cutting speed. Influence of the approach angle is less on the surface roughness of the metal matrix composite. Presence of lubricating property reinforcements like graphite enhances the surface finish due to the reduction of friction and its presence improves the machinability. Feed rate offers prime influence on the surface roughness of the composite. Optimization of machining parameters, nose radius and operation conditions are very important for minimize the tool wear, maximize the metal removal rate and better machinability. Nowadays there is progressing focus on reinforcements in nano scale like carbon nanotube (CNT), nano SiC and Graphene are significantly increased due to the improvement of mechanical, thermal and physical properties of the hybrid composite. Machining of the above hybrid composites not adequately addressed.

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