

Effect of Cutting Parameters on Thrust Force and Surface Roughness in Drilling of Al-2219/B₄C/Gr Metal Matrix Composites

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Abstract. In aluminium matrix composites, reinforcement of hard ceramic particle present inside the matrix which causes tool wear, high cutting forces and poor surface finish during machining. This paper focuses on effect of cutting parameters on thrust force, surface roughness and burr height during drilling of MMCs. In the present work, discuss the influence of spindle speed and feed rate on drilling the pure base alloy (Al-2219), mono composite (Al- 2219+8% B₄C) and hybrid composite (Al-2219+8%B₄C+3%Gr). The composites were fabricated using liquid metallurgy route. The drilling experiments were conducted by CNC machine with TiN coated HSS tool, M42 (Cobalt grade) and carbide tools at various spindle speeds and feed rates. The thrust force, surface roughness and burr height of the drilled hole were investigated in mono composite and hybrid composite containing graphite particles, the experimental results show that the feed rate has more influence on thrust force and surface roughness. Lesser thrust force and discontinuous chips were produced during machining of hybrid composites when compared with mono and base alloy during drilling process. It is due to solid lubricant property of graphite which reduces the lesser thrust force, burr height and lower surface roughness. When machining with Carbide tool at low feed and high speeds good surface finish was obtained compared to other two types of cutting tool materials.

1. Introduction

Machining of aluminum alloy composites containing hard ceramic particles in the matrix has a poor surface finish, high tool wear and burr height. Metal matrix composites rapidly replacing the conventional materials in various fields from automotive to aircraft components. Aluminum matrix composites (AMCs) can be successfully prepared by liquid metallurgy route, which is simple, economical and low cost compared to other methods. [1, 4]. Hybrid MMCs are obtained by reinforcing the matrix alloy with both ceramic and graphite particles to obtain improved mechanical and tribological properties as graphite is a solid lubricant. Many of the researchers highlighted the effect of cutting parameters such as drill speed, feed rate, drill diameter; drill bit material etc. to get an optimal solution to improve drilling process during machining of MMCs causes rapid tool wear due to generation of high temperature at the interface. When machining at higher depth of cut and increase in feed rate causes higher cutting forces, and surface roughness and flank wear. Basavarajappa et al. [2]



investigated the surface roughness of the drilled surface with different cutting parameters and cutting tool material. Extension of surface and subsurface deformation is studied due to drilling. Experimental results reveals that graphitic composites (Al2219/15%SiC/3%Gr) exhibited the lesser thrust force, burr height and higher surface roughness when compared to other material (Al2219/15%SiC) this is due to the solid lubricating property of graphite particles. Higher surface roughness is obtained in (Al2219/15%SiC/3%Gr) composite was due to graphite particle pullout from the surface. The surface roughness decreases with the increase in cutting speed and increases with the increase in feed rate. The results revealed that feed rate had a major influence on thrust force, surface roughness, and exit burr formation. Kumar Abhishek et al. [3] studied the machining parameters with multiple performance characteristics in drilling hybrid metal matrix Al356/SiC-mica composites to optimized by Taguchi method with grey relational analysis was used. The results indicated that the integrated approach presented in this paper can be effectively applied for continuous quality improvement and off-line quality control in any manufacturing process which involves multiple response characteristics correlated with each other. Muniraj et al. [4] presents a paper on drilling of aluminum metal matrix composites.(Al/15%SiC/4%Gr) The experiment conducted at different cutting parameters such as spindle speed and feed rate to study the effect of surface roughness and thrust force using coated carbide twist drill and carbide multifaceted drill of 4mm diameter. The results reveal that feed rate has a significant factor on thrust force and surface roughness.

Suresh et al. [5] presents a paper on turning of hybrid aluminum composites (Al+B₄C+Gr) using grey fuzzy algorithm. Better machinability and wear resistance is obtained in case of hybrid aluminum alloy composites containing graphite particles. Grey fuzzy logic approach gives less uncertainty in output when compared to grey relational technique. Basavarajappa et al. [6] presented a paper on surface integrity when drilling Al2219/15%SiCp and Al2219/15%SiCp-3%Graphite (hybrid) composites with different tools and cutting conditions. The surface roughness of hybrid composite is high when compared to mono alloy. Results concluded that coated carbide tool is better than multifaceted carbide tool. The SEM image reveals that existence of micro-cracks, particle pull out and shearing of particles. The subsurface deformation is less in hybrid composites when compared to mono composite. The multifaceted carbide tool performs better in terms of subsurface deformation. Navanath et al. [7] studied drilling of Al 2014 alloy using HSS twist drills under dry cutting conditions. By applying Analysis of variance (ANNOVA) to determine the significant factors affecting surface roughness and hole diameter. Spindle speed, feed rate and cutting tool materials were selected as control factors. Input variables and their interaction effect measured are found to be very close to predicted values. Venkata Lakshmi et al. [8] studied the performance characteristics such as circularity, spatter, HAZ and Taper for LMD of Al7075/10%SiCp metal matrix composite. Taguchi method and Grey relational analysis considered for Optimization method. Confirmation test results validate the test results. Rodrigues Kantharaj et al. [9] Investigated speed, feed and depth of cut on surface roughness in turning mild steel the feed rate has significant influence on both the cutting force and surface roughness. Thrust force increases with increase in depth of cut.

Suresh et al. [10] presents a paper on metal matrix composites reinforced with graphite particles in turning of Al-SiC-Gr hybrid composite using Grey fuzzy algorithm. The performance characteristics of such as feed rate, cutting speed, depth of cut and mass fraction of reinforcement. As the increase in feed rate the surface roughness is also increases. Surface roughness found to be directly proportional to feed rate and inversely proportional to cutting speed. The addition of graphite particles reduces ductility and hardness, machining is easy with maximum MRR and less tool wear. Anand Babu et al. [11], presented a paper on drilling of aluminum matrix composites (Al7075/10% SiCp) Taguchi L₂₇ orthogonal array has been applied on coated and uncoated carbide tool, surface roughness is predicted using fuzzy logic. Both experimental and predicted surface roughness values are very close to each other. It can be concluded that feed has a significant factor on surface roughness in addition to point angle, tool material, speed and cutting environment. In the present work, discuss the influence of spindle speed and feed rate on drilling the pure base alloy (Al-2219), mono composite (Al-2219+8%B₄C) and hybrid composite (Al-2219+8%B₄C+3%Gr). The composites were fabricated using stir casting method. The drilling experiments were conducted by CNC machining center with TiN coated HSS, M42 (Cobalt grade) and carbide tools at various spindle speeds and feed rates

2. Materials and experimentation

2.1. Materials and methods

Al 2219 is used as a matrix material; it is an Al-Cu binary alloy and excellent weld ability as weld strength. This alloy is suitable for high strength and high temperature applications in aerospace and automobiles. Due to high thermal conductivity, it has good heat dissipating capacity. The constituents of Al 2219 are shown in Table 1. The materials Al2219, Al2219/8percentageB4C and Al2219/8percentageB4C/3percentageGr were fabricated by liquid metallurgy route. The B4C particles of 90 microns and graphite of 60 microns were used as reinforcing materials. Liquid metallurgy route is suitable for fabrication of MMCs for uniform dispersible of reinforcing particles and cost of fabrication is as low as 1/3 to 1/10 of other process. K₂TiF₆ halide salt is added in order to improve the wettability. Fig 1(a) and (b) shows FESEM image of Al+B₄C and Al+B₄C+Gr that uniform distribution of reinforcing particles in the image.

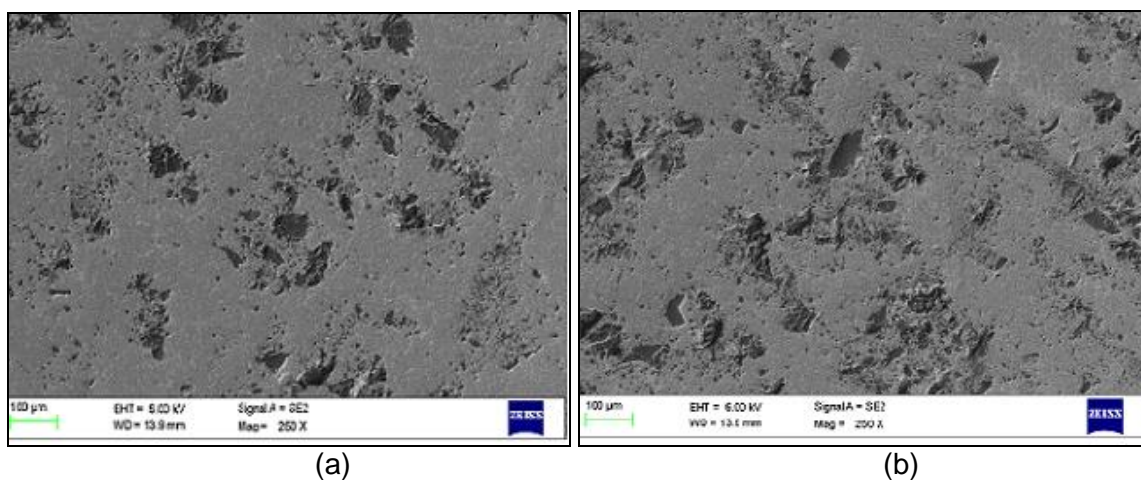


Figure 1. SEM images of (a) Al+B₄C, (b) Al+B₄C+Gr composites.

Table 1. The constituents of Al 2219 alloy

Elements	Mg	Si	Cu	Zr	Fe	Zn	Ti	V	Zn	Al
Weight%	0.02	0.20	5.96	0.18	0.3	0.10	0.08	0.095	0.1	Bal.

2.2. Experimental Procedure

The experiments are carried out on CNC vertical milling machine (MITBASHI). The details of cutting tools, work materials and machining parameters used for the conducting the experiments are given in Table 2. The prepared castings of size 100 mm x 50 mm x 10 mm was mounted on a drill tool dynamometer (Kistler 9257B) with suitable fixture on the machine as shown in Figure 2. The thrust force was measured using a data acquisition system (DAQ). The maximum thrust force was taken as a mean of reading taken from start to end of drill process. The surface roughness (R_a) of the drilled hole was evaluated using surf-test: SJ-201 having a cut-off length of 0.8 mm. Liner plate of 10 mm is kept below the work piece and drill dynamometer to prevent damage of dynamometer and to prevent burr during drilling test. The burr height is measured by using dial indicator of 0.001mm accuracy at three different positions along the circumference of the drilled hole on work piece. Average reading was taken. Chips were collected during drilling process and examined for general characteristics.

Table 2. Summary of Experimental Conditions

Machine	MITBASHI Machining Centre	
Drill tool material	Tin , M42 and carbide tool	All drill bits of 5mm diameter
Work piece Materials	Al2219, Al2219/8%B4C and Al2219/8%B4C/3%Gr	
Cutting Conditions	Feed rate: 0.1, 0.20 and 0.30 mm/rev; Cutting Speed: 1000, 1500, 2000 rpm; Depth of hole drilled: 10 mm	

**Figure 2.** Experimental setup with drill tool dynamometer and DAQ system

3. Results and Discussion

3.1. Effect of cutting parameters on thrust force

Drilling parameters such as cutting speed and feed are two important factors considered in machining. Figure 3 shows that variations thrust force with increase in feed rate for various speeds of 1000, 1500, and 2000 rpm with 3 types of drill bits. The results reveal that as feed rate increase from 0.1 to 0.3 mm/rev the thrust force increases for all the speeds for all composite materials. Higher the thrust force was observed at higher the feed rate. There is no predominant variation in thrust force on increasing the speed for all the feed rates. Similar variation is found by Basavarajappa et al. [2] reported that drilling forces are influenced by feed rate when drilling both Al2219/15% SiC and Al2219/15%SiC/3%Gr using uncoated carbide and TiN coated carbide drill bits. The fig.4 shows the variation thrust force when machining three types of materials, thrust force is high when machining Al2219/8percentageB4C composite when compared to Al2219/8percentageB4C/3percentageGr for all cutting conditions and for all the types of tools. High thrust force is due to reinforcement of hard ceramic particles distributed uniformly in the matrix material. In hybrid composite material thrust force decreases due to presence of graphite particles as a solid lubricant. The interfacial friction between tool and work piece reduces in case of hybrid composites Hardness value of hybrid composite is less than mono composite low value of hardness and strength improves the machinability, poor surface finish and burr formation. Carbide tool shows less thrust force compared to M42 (cobalt grade) and TiN coated HSS drill bits for all cutting conditions.

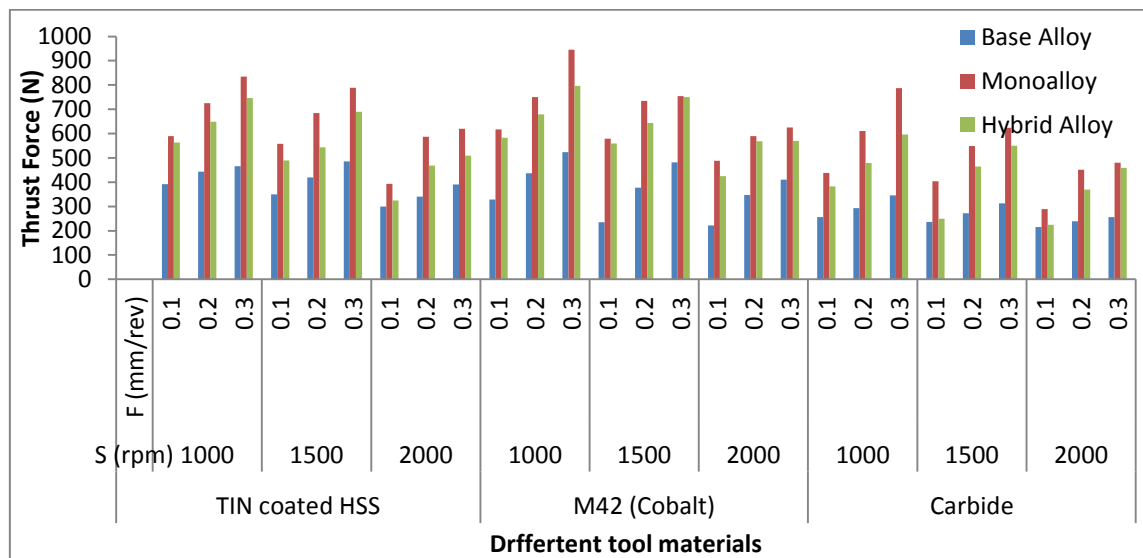


Figure 3. Effect of cutting parameters on thrust force during drilling of composites using different cutting tools

3.2 Effect of cutting parameters on surface roughness

Figure 4 shows the variation of surface roughness with various spindle speeds and feed rates using TiN coated HSS, M42 (cobalt grade) and carbide drill bits. The surface roughness values for mono composite increases with the increase in feed rate and decreases with increase in spindle speed. It is observed that when drilling with all the three types of tools feed rate is more dominant than spindle speed. Surface roughness value for hybrid composite is more than that of mono composite for all the cutting parameters and drill bits. In case of hybrid composite particle pullout and formation of deep valleys are formed on the surface during lower cutting conditions. At higher speeds surface roughness value decrease due to burnishing or honing effect produced by rubbing of small particles of B4C trapped between tool and work piece surface [9].

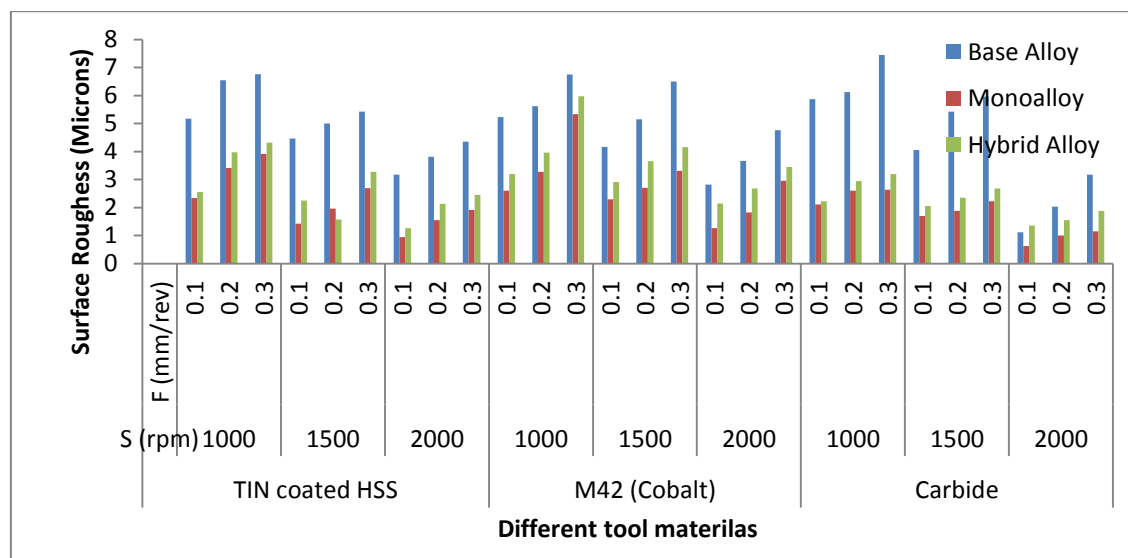


Figure 4. Effect of cutting parameters on surface roughness in drilling of composites with different cutting tools

3.3 Effect of cutting parameters on burr formation

Figure 5 shows the effect of cutting parameters on burr height during drilling of composites using different cutting tools the burr height formed in drilling base alloy, mono alloy and hybrid alloys. As the feed rate increases from 0.1 to 0.3 mm/rev, the exit burr height increases. The burr height found to be more in case of mono composite (Al2219/8percentageB4C) when compared to hybrid composites. (Al/B4C/Gr). At low feed rate the thrust force is less due to less plastic deformation. Presence of graphite particles in hybrid composites reduces burr height. The burr produced is less in drilling with carbide tool, when compared to TiN, and M42 tool for all the cutting parameters.

Figure 6 shows the difference in burr heights when drilling with composites with all the three types of drill tools. The interfacial bond forms in-between B4C and work piece material .when the drill tool lip area penetrates into the material. A crack propagates and reaches the edges of the hole as Al alloy weakens (yields). At a higher feed rate ($f=0.3\text{mm/rev.}$) the reduction in interfacial bond between B4C and Al alloy is less and burr initiation is delayed. Thrust force increases at faster rate, the matrix alloy yields and lesser number of B4C particle induced cracks are formed. Larger burr height is formed when pivot point is at the matrix alloy. When larger thrust force transmitted to the work piece through drill lip area under the drill bit B4C particles present are pulled out or sheared .Material yields owing to the reduction in interfacial bond between B4C and matrix material.

Graphite particles smears out under plastic deformation due to low interfacial bond strength as the drill advances and when B4C or graphite particle forms the pivot point, a burr height of reduced height is formed. The increase in feed rate increases the thrust force. The larger thrust forces responsible for larger burr formation before interfacial bond cracking progress. Graphitic composites shows less burr height when compared to Al2219/B4C reinforced composites. In drilling with Tin coated HSS a large thrust force is developed compared to M42 and carbide tool, so larger burr height is formed.

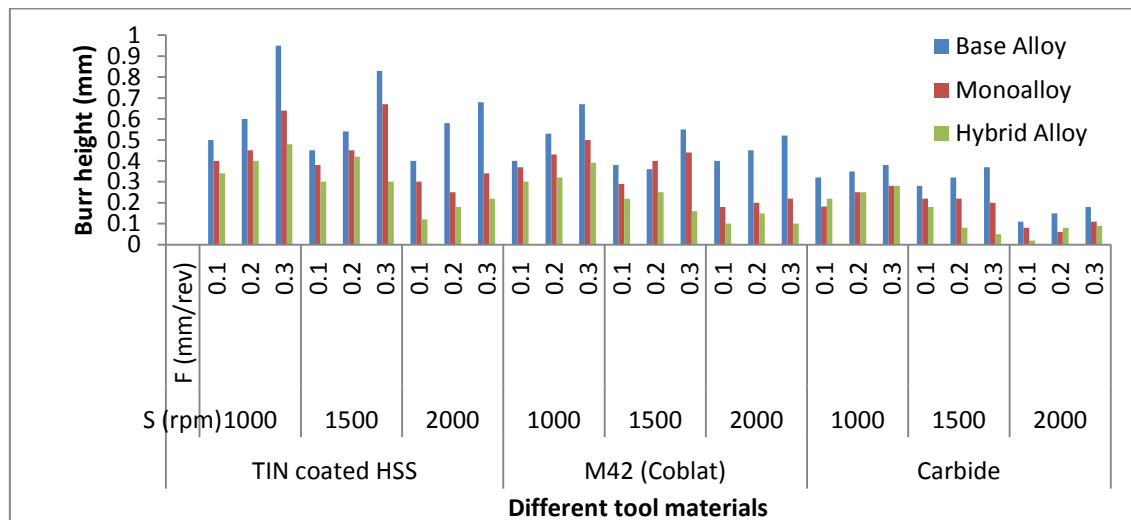


Figure 5. Effect of cutting parameters on burr height during drilling of composites using different cutting tools



Figure 6. Burr heights observed on drilling of (a) Base Alloy (b) Mono alloy and (c) Hybrid alloy with TiN coated HSS, M42 and carbide drill bits

3.4 Chip formation

Machined surface finish depends upon types of chips formed; the chip formation studies shows the factors influencing the tool wear and surface roughness. During drilling process, chips were collected and examined for general features. Figure 7 shows the chip formation for all the types of composite material when drilled with carbide tool with high spindle speed of 2000 rpm and higher feed rate of 0.3 mm/rev. The drilling pure base alloy continuous curled chips were obtained during drilling. It is due to ductility of base alloy Al2219. In case of Al2219/B₄C, it is observed that the length of chip formed is smaller in length with curls and serrated chips are formed. This is because of addition of B₄C particles increases the brittleness of the composite. Chips formed are of saw tooth type curls, cracks propagate along the B₄C particles interface. When these cracks propagate and reach the edges of the chip, fracture occurs resulting in the formation of discontinuous chips and even B₄C particle pull out during machining. The regions of particle pull out act as a crack initiation points as curls with advancement of tool. These cracks propagate results in fracture of chips with advancement of tool. Discontinuous chips are formed in mono composite. When machining hybrid composite the chips obtained are short and no curls are formed. The chip disposal is easier from the machined surface. Both hard ceramic and soft graphite particles act as regions of crack propagation, which acts as a chip breaker. On observing the nature hybrid composites chips are discontinuous shorter in length and series of chips are loosely attached to each other.

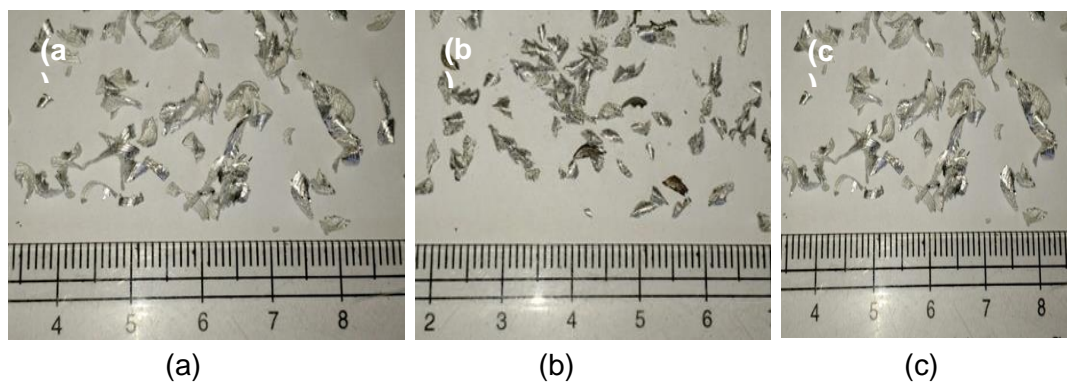


Figure 7. Chip produced in drilling of (a) Base alloy (b) Mono alloy and (c) Hybrid alloy with carbide drill at speed of 2000 rpm and feed of 0.3mm/rev

4. Conclusions

The important findings are summarized as follows:

- Graphite present in hybrid composite as a reinforcement material in Al2219 reduces thrust force.
- Feed rate has a substantial influence on thrust force, surface finish and burr height.
- Increase in feed rate increases the surface roughness value and decreases with the increase in cutting speed.
- Poor surface finish is obtained when machining hybrid composites due to graphite particle pull out from the drilled surface.
- Graphitic composites show less exit burr height during drilling with carbide tool when compared to other types of drill tools.
- The chips formed in drilling mono, hybrid composites are of discontinuous type, and it is easier for chip disposal.

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