Experimental Investigation of Drill Point Geometry in Drilling of Metal Matrix Composites

Sarbjit Singh, Inderdeep Singh, Akshay Dvivedi* and Pradeep Kumar
Indian Institute of Technology Roorkee, Uttarakhand, India
* akshaydvivedi@gmail.com

Abstract

The hard abrasive particles such as silicon carbide and aluminum oxide present in metal matrix composites make them unsuitable for secondary processing. The presence of these particles leads to frequent tool wear and high value of cutting forces. An increase in surface roughness was also observed with the increase in cutting forces and tool wear. This paper is an attempt to study the effect of different drill point geometries of solid carbide on the cutting forces, tool wear and surface roughness in drilling of Al6061 SiCp Metal Matrix Composite (MMC). During investigation it was observed that the Jo- drill provides better results as compared to four facet and parabolic drill. During drilling at high speed and feed rate, it was found that the thrust force is 3-4 times higher than the lower speed and feed rate combination for the same drill point geometry. A correspondingly increase in surface roughness was observed in the range of 1.5- 2.5 times as compared to the lower speed and feed rate combination.

Keywords - MMC, BUE (Built up edge), Jo-drill, Four Facet Drill, Parabolic Drill.

Introduction

A family of advance materials with properties superior to conventional material has been developed over the past decades. One of these advanced materials is metal matrix composite (MMC). These advance material possess attributes that make them attractive for use. The attributes including a combination of the following properties like, a high strength to weight ratio, a high elastic modulus, high toughness and impact strength, low sensitivity to temperature change or thermal shocks, high surface durability and low sensitivity to the surface flaws among other conventional materials (Monaghan and Reilly, 1992; Dvivedi *et al.*, 2008). As a result, many of the current and foreseeable applications for MMCs are in aerospace and automobile components, where the service environments are demanding and dynamic loading is common (Dvivedi *et al.*, 2008). Machining is one of the highest costs associated with the fabrication of composites from MMCs. This is because the high hardness and abrasive ceramic reinforcing material leads to high tool wear rate when using conventional high speed steel tools. Consequently, the development of effective machining method, which leads to a reduction in the overall cost of MMC components, is one of the major challenges yet to be solved. However, for joining and assembling, secondary machining processes such as drilling are required. Drilling is often the last manufacturing process to be performed on a part before assembly. Monaghan and Reilly, 1992 found that the best performance was obtained from PCD tools and the flank wear was below the recommended value. Mubaraki *et al.*, 1995 found that in PCD drills flank wear of 0.12 mm was seen after 2210 second of drilling and its beginning occurs after 720 s after that it was increased marginally Edith Morin *et al.*, 1995 found that wear was directly related to the reciprocal of the feed rate and was found to be independent of the cutting speed. A experimental and numerical study based upon the genetic algorithm was carried out by Davim and Antonio, 2001 and it was observed that the wear develops on the flank face of the drill. The predominant wear mechanism is abrasive which leads to increase in feed force with the increase in the tool wear. A Taguchi approach was applied by Davim, 2003 to study the influence of cutting parameters and cutting time on drilling of metal matrix composites and it was found that cutting time is the factor which has a higher influence on the tool wear (50%) followed by feed rate (24%). Monaghan and Reilly, 1992 found the lowest forces were recorded for the test performed using PCD drills, followed by the carbide and HSS tools. The order of these results indicates clearly that tool hardness has a major influence on the efficiency of drilling process when machining MMC materials. The torque results also show the similar trends (Monaghan and Reilly, 1992). Morin *et al.*, 1995 found that while drilling with unworn drills, both torque and thrust varied with feed rate raised to the power of 0.81. Ramulu *et al.*, 2002 found that the PCD drills produced lowest drilling forces in comparison with the drilling forces generated by carbide tipped drills. Drilling forces depends on the hardness of the reinforcement. As the volume fraction of the reinforcement increases significantly, regardless of the tool material and work material, both thrust force and torque were highly dependent on feed rate while cutting speed was found to have insignificant influence on the degree of drilling forces. Basavarajappa *et al.*, 2008 during working on hybrid composites found that the thrust force is high when machining Al2219/15SiCp composites compared to Al2219/15SiCp-3Gr composites for all cutting conditions with both the carbide and coated carbide tools. The addition of 3% graphite reduces the thrust forces significantly. This is attributed to the solid lubricating property of the graphite particles. Basavarajappa *et al.*, 2008 used taguchi technique to find the effect of process variables on thrust force and found that feed rate is the main factor, which is influencing the thrust force. The cutting speed and its interaction with feed rate have minimum influence and therefore can be neglected. The incorporation of 3% graphite in Al/SiCp composite will reduce up to 25% of the thrust force for the range of parameters studied. Davim and Antonio, 2001 used experimental and numerical technique to optimize the process and found that during drilling PMMC discs, the feed force increases with the flank wear of the drills. The torque is not sensitive to the tool wear increase. Haq *et al.*, 2008 presented a new approach for the optimization of the drilling parameters while drilling Al/SiC metal matrix composites with multiple responses based on orthogonal array with grey relational analysis. It was found that the point angle, cutting speed and the feed rate are the prominent factors which effect the drilling of Al/SiC metal matrix composites. The statistical influence of the Point angle, cutting speed and feed on the output response surface roughness, cutting force and torque was found to be 43.21%, 28.64% and 26.21% respectively.

In this present pilot study an attempt was made to study the effect of different drill point geometry at extreme upper and lower process parameter conditions on the response tool wear, thrust force, torque and surface roughness.

Experimental Setup

Material

A volume fraction of 7.5% Si-Cp particulate reinforced in 6061 aluminium was used in the study. The microstructure of MMC is as shown in Fig. 1. Specimens of 100×20×7mm3 were used for drilling. The chemical composition of the material was as shown in the Table 1. The average Vickers hardness of 7.5% the material was 70

Table 1: Chemical composition of the material

Al	Si	Mg	Cu	Mn	Cr	Fe	Ti
95.83	0.68	1.20	0.61	0.45	0.50	0.27	0.46

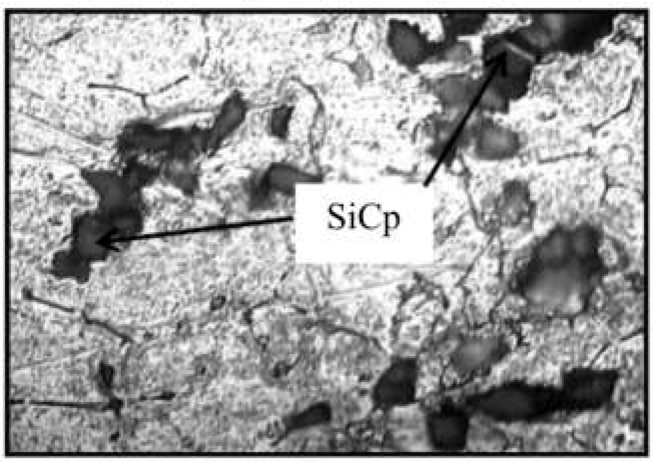


Figure 1: Microstructure of the work piece material (**Murthy, 2010)**

Experimental setup and procedure

Experiments were conducted on a radial drilling machine (Batliboi & Company Pvt. Ltd. Surat, India) having specifications as shown in Table 2. The tool material used was solid carbide. Three drills of 8mm diameter of different geometry, namely four facet, parabolic and jo-drill were used. The geometrical details of the tool geometry are as shown in Fig. 3 (A, B, C). The tests were carried on 7.5% SiCp reinforced using solid carbide drills and performed at different combination of machine tool parameters.

Table 2: Specification of the machine tool

Speed ranges	90 – 900 rpm (6 No.) 450 – 2800 rpm (6 No.)
Feed range	0.03–0.3 mm/rev (6 No.)
Drilling main motor power / speed	1.5 kw / 1420 rpm

Dry drilling was performed at different feed and speed combination with each set of drill. Force (F_z) and torque (M_z) signals was recorded using four component piezoelectric drill dynamometer (Kistler, 9272).

Results and Discussion

Fig. 2 shows different holes drilled in the specimen. During drilling operation chattering noise was noted in all the three drills. It is because of interacrion of the cutting edge with the abrasive SiC reinforced particle. corresponding to that chattering noise the drill dynamometer shows a steep rise in cutting forces.

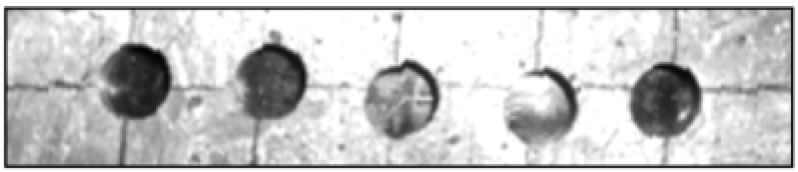


Figure 2: Drilled specimens

Tool wear

During drilling operation of multiphase material like MMC, the cutting edge experienced abrasion as well as force fluctuation due to grinding of harder abrasive particles. Fig. 3 shows the photo graphs of the unused drill points and the worn drill points after the experimentation. From the Fig. 3 it was clear that a relatively stable built up edge (BUE) was formed during drilling of metal matrix composites on the chisel edge and flank edges. These stable built up edges provide an extra cutting edge and protect the cutting edge of the tool from wear. Wear of the tool decreases with the formation of built up edge but correspondingly there is an increase in the cutting forces and the quality of the hole produced deteriorates.

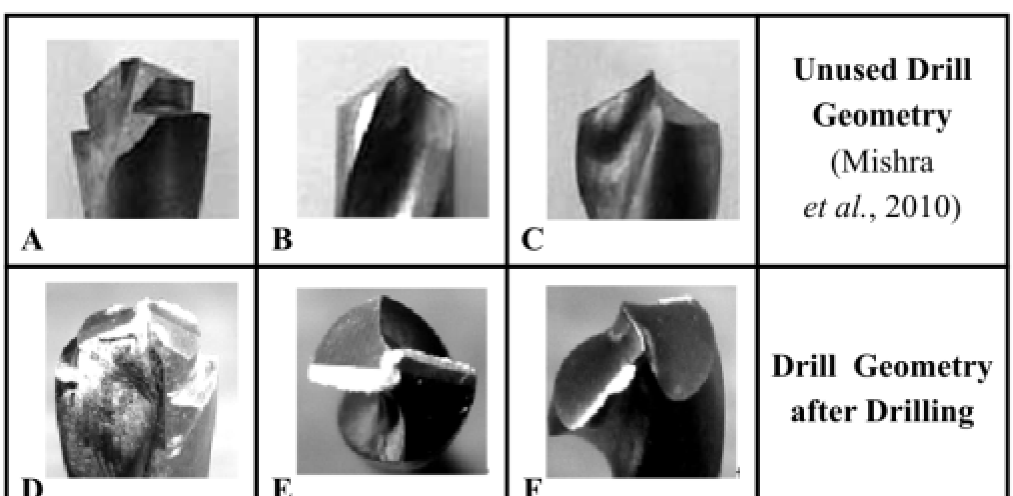
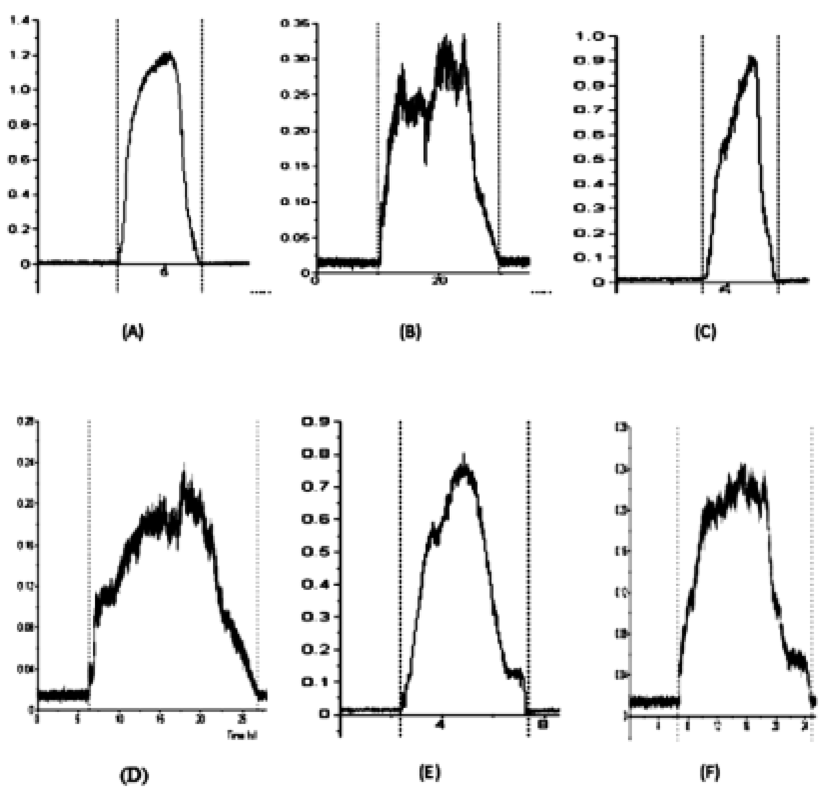


Figure 3: Photographs of unused drill bits and after the experimentation

Thrust forces

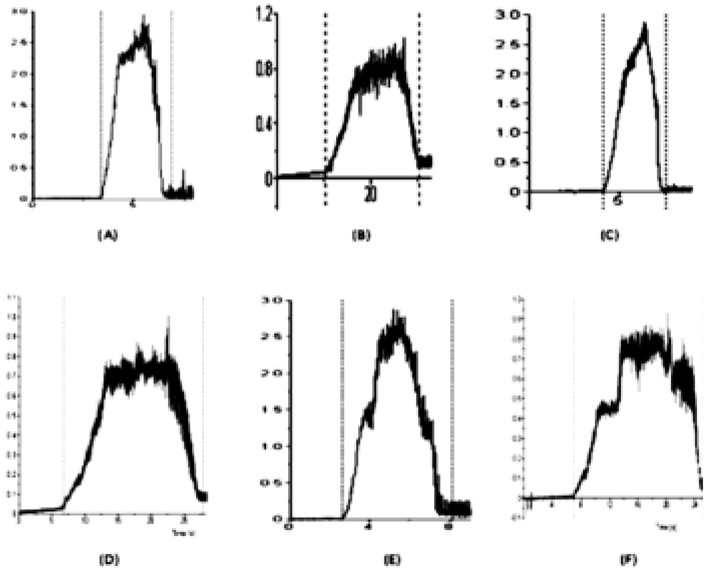
Fig. 4 shows the variation of thrust force with different profile of drill point at various combination of cutting speeds and feed rates. For four facet drill point at high speed and high feed the cutting force was 1.22 KN and at low speed and low feed was 0.34 KN and corresponding surface roughness of the hole was 4.0005 Ra and 2.9 Ra. For parabolic drill at high speed and high feed the cutting force was 0.92 KN and at low speed and low feed was 0.24 KN and corresponding surface roughness of the hole was 5.0425 Ra and 3.2625 Ra. For Jo-drill at high speed and high feed the cutting force was 0.8 KN and at low speed and low feed was 0.25 KN and corresponding surface roughness of the hole was 2.3525 Ra and 0.986 Ra.

From the above data it was concluded that at high speed and high feed using four facet drill the thrust forces are 3.6 times greater than at low speed and low feed, and increase in surface roughness was approximately 1.4 times compared to low speed and low feed. For parabolic drill the thrust forces are 3.8 times greater than at low speed and low feed, and increase in surface roughness was approximately 1.54 times compared to low speed and low feed. For Jo-drill the thrust forces are 3.2 times greater than at low speed and low feed, and increase in surface roughness was approximately 2.38 times compared to low speed and low feed.



(A) High speed high feed facet drill, (B) Low speed low feed four facet drill,
(C) High speed high feed parabolic drill, (D) Low speed low feed parabolic drill,
(E) High speed high feed Jo-drill, (F) Low speed low feed Jo-drill

Figure 4: Variation of force at different combination



(A) High speed high feed four facet drill, (B) Low speed low feed four facet drill,
(C) High speed high feed parabolic drill, (D) Low speed low feed parabolic drill,
(E) High speed high feed Jo-drill, (F) Low speed low feed Jo-drill

Figure 5: Variation of torque at different combination

Further, with relative to Jo drill at high speed and high feed the four facet drill exhibit approximately 50% higher force and parabolic drill exhibit approximately 12% higher force. At low speed, with relative to jo- drill the four facet drill exhibit 14% higher force and parabolic drill showed decrease in cutting forces. A high value of surface roughness was observed in parabolic and four facet drill as compared to Jo-drill. In all the experiments performed on extreme condition with different drill point geometry, it was observed that there was an increase in thrust forces at higher feed and higher speed as compared to low speed and low feed. It was also observed that the quality of the drilled work piece deteriorates. The increase in thrust forces at higher feed and higher speed is because drill point has to remove more material per revolution at higher feed and high speed as compared to low feed and low speed. There was simultaneously decrease in the quality of the drilled hole because of decrease in honing effect at higher feed (time for interaction of abrasive particles with work piece decreases)

From this experimental run it was concluded that Jo- drill provide a minimum force as compared to parabolic and four facet drills. The high value of thrust force produced in four facet and parabolic drills may leads to increase in the vibration (natural frequency) of the cutting tool. The effect of increased vibration of the machine tool may be one of the causes of decrease in the quality of the drilled hole.

Torque

The torque signals produced by the same set of drills are as shown in the Fig. 5. With reference to the jo- drill at high speed and high feed, in the four facet drill and in the parabolic drill considerable amount of variation of torque was not recorded. It was in the range of +- 5% with respect to jo-drill. Same was the case when torque value at low feed and low speed was considered. For low speed and low feed rate the variation of torque with respect to jo-drill was 20% and14% for four facet and parabolic respectively. But the variation was considerable when data was compared for same drill at high speed high feed with low speed low feed and it was observed that it was 160%, 200%and 225% higher than at low speed and low feed for four facet, parabolic and jo-drill respectively.

Conclusion

A stable BUE was developed in all the drills used which cause the increases in thrust forces, torque and surface roughness. This stable BUE increases the thrust force, torque and surface roughness; however, it also protects the cutting point of the drill point geometry from excessive wear. The performance of Jo-driil was found better as compared to four facet and parabolic drills under similar experimental conditions. In all type of drills a decrease in cutting forces and surface roughness was observed when used at lower value of the process parameters.

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