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Original Research Article

Effect of cutting parameters on cutting forces for turning of Al/garnet/graphite metal matrix composites

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ABSTRACT

Metal matrix composites are gaining the special interest of researchers. But machining of metal matrix composites is too difficult. The present study is focused on effect of cutting parameters on cutting forces for turning of aluminium/garnet/graphite particulate metal matrix composite material. The turning operation was performed on various volume fraction of composite at different cutting conditions and effect of process parameters on the machining characteristics such as cutting force, feed force, thrust force and tool wear. The liquid metallurgy technique was used to fabricate the composites. The result obtained shown that increase in feed rate, depth of cut and increases the cutting forces. It was also found that 12% reinforcement of graphite decreases has low cutting forces for the variation of cutting speed and feed rate, but cutting forces were high for variation in depth of cut. The analysis of tool wear shown that tool wear was less for low reinforcement. Tool wear increases with the increased in speed and depth of cut and decreases with the increase in feed.

1. Introduction

Metal matrix composites (MMCs) offer designers many added benefits. They are particularly suited for applications requiring good strength, good structural rigidity, dimensional stability, low coefficient of thermal expansion and lightweight. Reinforcement of ceramic particles in MMC's has attracted considerable interest from scientist and engineers. The MMCs shown substantially improved elastic modulus, strength, stiffness and tribological properties with low coefficient of thermal expansion compared with the unreinforced matrix material [1]. Considerable research in the field of material science has been directed towards the development of new light-weight, high performance engineering materials like composites. The applications of these composite materials are among the most important developments in material engineering in recent years, MMCs are one among them.

MMCs has become necessary materials in various engineering applications like aerospace, marine and automobile industries, because of their light-weight, high strength, stiffness and resistance to high temperature. The applications of MMCs are limited by poor machinability, due to its highly abrasive nature. It causes excessive tool wear in machining of ceramic particles reinforced aluminium matrix composites with tungsten carbide tools and even with diamond tools. Although attempt have been made to eliminate machining operations by using fabrication techniques like near net shape forming and modified casting, they are eliminated

and therefore machining is still an integral part of the component manufacture. However, in view of the growing engineering applications of these composites, a need for detailed and systematic study of their machining characteristics and machinability was envisaged. By controlling the various parameters, which influence the machinability, intended surface finish, reduced tool wear and cutting forces could be obtained.

From the available literature on machining MMCs, it is obvious that the morphology, distribution and volume fraction of the reinforcement phase as well the matrix properties, are all factors that affect the overall cutting properties [2]. A continuing problem with particulate MMCs is that they are difficult to machine, due to the hardness and abrasive nature of the garnet or other reinforcing particles. The ceramic particles used in MMCs are harder than tungsten carbide (WC), the main constituent of the hard metal and even than the majority of cutting tool materials. The presence of hard ceramic particles in the composites makes them extremely difficult to machine as they lead to rapid tool wear. The hard-garnet particles in ZA-27/garnet MMCs, which intermittently comes in contact with the tool surface and acts as small cutting edges like those of grinding wheel on the cutting tool edge. These particles act as abrasives between cutting tool and work piece and resulting in formation of high tool wear, poor surface finish, high cutting forces and burr formation.



Davim has conducted drilling tests with intention of developing optimal drilling conditions using genetic algorithm approach and noticed a predominantly abrasive wear mechanism attributed to the hard particles in the matrix [3]. The surface finish was found to be affected by the feed and not by the cutting speed. Ramulu et. al. [4] reported that the alumina particulates caused extremely rapid flank wear in drilling tools, when machining Al₂O₃ particulate reinforced aluminium-based MMCs. Among the three tool materials studied, polycrystalline diamond (PCD) drills possessed the highest resistance tool wear and they are recommended for finish machining operations under most cutting conditions. The carbide tipped drill also showed acceptable drilling forces and hole quality. In this case, carbide tipped drills can be used under compromised conditions. HSS drills are unsuitable for drilling of ceramic reinforced MMCs because of very high tool wear, poor hole quality and higher drilling forces induced [5–6].

In view of the above, an attempt has been made in this investigation to study the effect of graphite particles on

machinability of ZA-27/garnet MMCs. The Taguchi design of experiments and analysis of variance were used to find the percentage of influence of various factors and their interaction on turning of the composites.

2. Experimental Procedure

2.1 Materials

In the present study, ZA-27 alloy having a chemical composition as per the ASTM B669-82 ingots specification, given in Table 1 was used as the base matrix alloy. The reinforcement material used was garnet, which is basically a silicate, abundantly available and having Mohr’s hardness of 6.5 to 7.0. Garnet has high hardness and excellent thermal stability and is less expensive than the SiC whiskers and Al₂O₃. It is composed of alumina-silicates of calcium and it does not react in chemical solution. ZA-27/garnet/graphite reinforced composites were fabricated by liquid metallurgy technique [9-15].

Table 1: Chemical composition of ZA-27 alloy.

Compositions	Al	Mg	Cu	Fe	Zn
%	25.0-30.0	0.012-0.020	2.0-2.5	0.075	Balance

2.2 Test set up

A lathe with 6kW spindle power was used to perform the experiments. The tungsten carbide inserts were used to turn MMCs specimen of 75mm diameter is as shown in figure 1. The geometry of the cutting tool used in the experiment was as follows: rake angle 60° and 0°, clearance angle 7°, major cutting-edge angle 60° and cutting-edge inclination 0°.

A Kistler piezoelectric dynamometer with appropriate load amplifier was used to monitor the cutting forces. Several different programs for data acquisition have been developed. They allow direct and continuous recording and simultaneous graphical visualization of the evaluation of cutting force, feed force and radial force. The cutting tool wear was measured (according to ISO 3685) with Mitutoyo optical microscope with 30X magnification and 1µm resolution. The surface roughness was evaluated (according to ISO4287/1) with a Homeltester T500 profilometer [16-18].

2.3 Test parameters

The test parameters considered for the study were cutting speed, feed rate and depth of cut. The levels of parameters

employed are shown in Table 2. The tests were conducted in three phases, in first phase feed rate and depth of cut are kept constant and cutting speed was varied. The cutting forces are noted down. In second phase speed and depth of cut were kept constant and feed rate was varied and in the third phase depth of cut was varied by speed and feed rate keeping constant. The tool wear for each trial was also noted for the study. The repeatability of wear test runs was established by determining the coefficient of variation which was well within the acceptable limit of 10%.

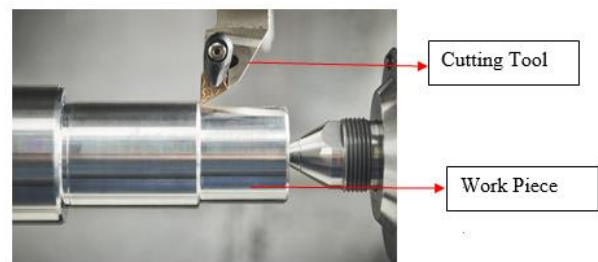


Figure 1: Experimental Setup.

Table 2: Machining parameters and their levels.

Levels	Cutting speed (in rpm)	Feed rate (in mm/min)	Depth of cut (in mm)
1	224	0.048	0.25
2	315	0.051	0.50
3	500	0.055	0.75
4	775	0.059	1.00
5	1200	0.062	1.25

3. Results and Discussion

3.1 Cutting velocity (S)

While studying the effect of cutting speed on tool wear, parameter such as feed rate and depth of cut are kept constant. Tool wear is one of the most important factors influenced by the cutting speed. While machining ZA27/garnet/graphite

using carbide tool, the experimental result reveals the fact that if the cutting speed increases, the flank wear also increases when comparing with its value at lower speed range. Tool wear increases with increase in particulate weight fraction. Tool life decreases with increase in cutting speed at all cutting condition, because for high cutting speed, the tool temperature

increases which softens the tool material. Cutting forces also increases with the increase in speed because of the increase in nose radius due to tool wear.

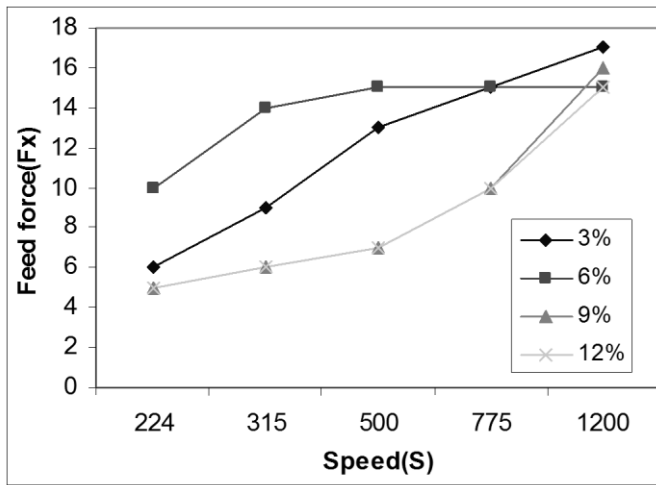


Figure 2: Effect of cutting speed and feed force while machining ZA-27 composite material.

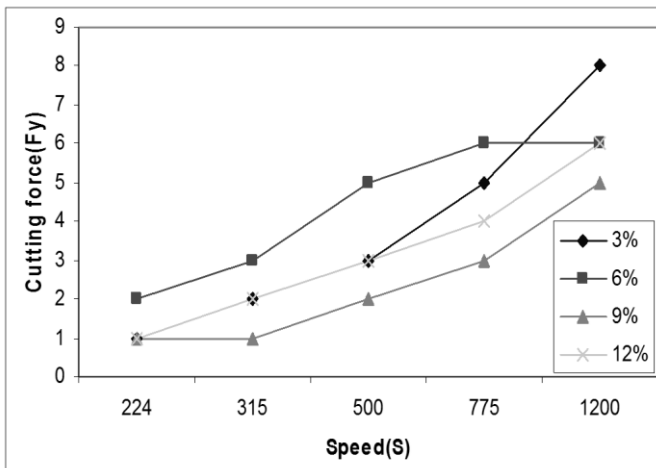


Figure 3: Effect of cutting speed and cutting force while machining ZA-27 composite material

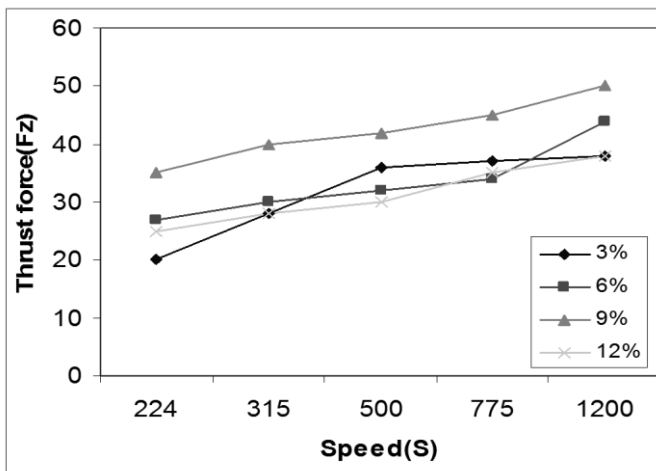


Figure 4: Effect of cutting speed and thrust force while machining ZA-27 composite material

Figure 2 shows the effect and results of cutting speed on feed force while machining ZA-27 alloy with garnet reinforced composite material. Figure 3 shows the effect and results of

cutting speed on cutting force while machining ZA-27 alloy with garnet reinforced composite material. Figure 4 shows the effect and results of cutting speed on thrust force while machining ZA-27 alloy with garnet reinforced composite material.

From the experimental data it was observed that the feed force, cutting force and thrust force increases with increase in speed rate. This is because cutting forces for low chip loads are higher, i.e. material removal is more energetically expensive at light chip loads. The increase in cutting force must come from the reduction in effective friction at the tool-chip interface [7].

3.2 Feed rate (f)

Feed rate has less influence on the tool wear than surface finish. A high feed rate can reduce the tool wear because it improves the conduction of heat from the cutting zone to the work piece. Figure 5 shows the effect and results of feed rate on feed force while machining ZA-27 alloy with garnet reinforced composite material. Figure 6 shows the effect and results of feed rate on cutting force while machining ZA-27 alloy with garnet reinforced composite material. Figure 7 shows the effect and results of feed rate and thrust force while machining ZA-27 alloy with garnet reinforced composite material. Figure 10 shows the effect of feed rate on tool wear while machining ZA-27 alloy with various percentage of garnet reinforced composite material.

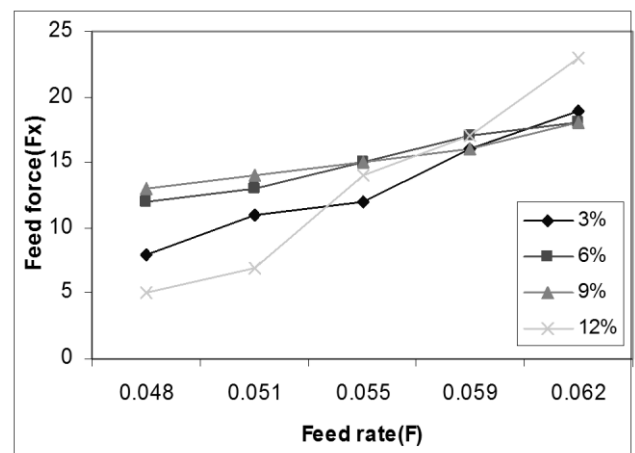


Figure 5: Effect of feed rate and feed force while machining ZA-27 composite material.

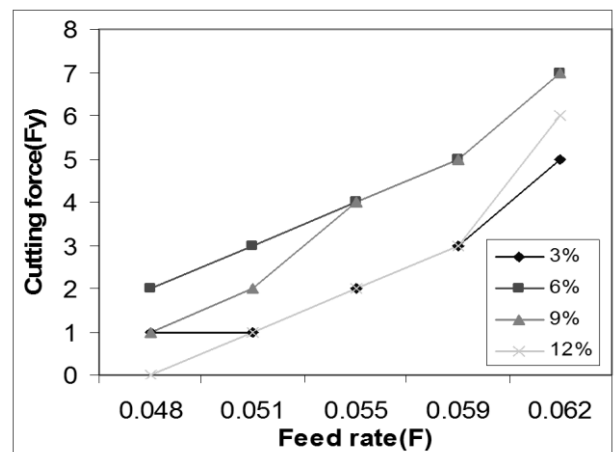


Figure 6: Effect of feed rate and cutting force while machining ZA-27 composite material.

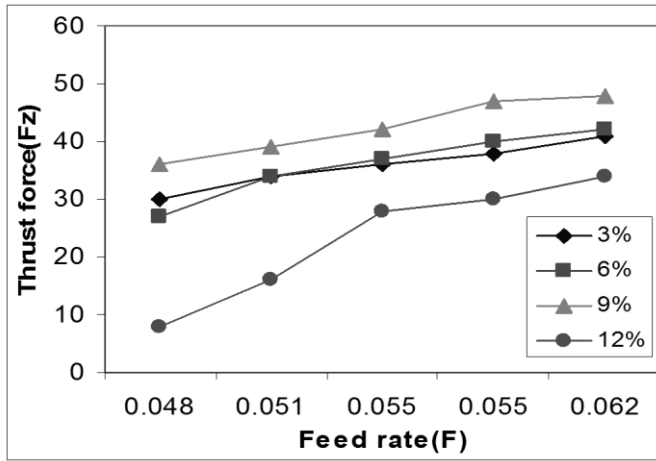


Figure 7: Effect of feed rate and thrust force while machining ZA-27 composite material.

From the experimental data it was observed that the feed force, cutting force and thrust force increases with increase in feed rate. Both feed and cutting forces are lower at low feed rates. At lower feed rates, the rate of increase in cutting force and thrust force was slower but at higher feed rates, the rate of increase in cutting force and thrust was faster. The increase in the cutting forces may be required at high feed rate, since it needs high force for cutting more number of hard particulates in short interval of time. A high feed rate can reduce the tool wear rate because it improves the conduction of heat from the cutting zone to the work piece. As the feed rate increases the flank wear increases, but the feed rate is less susceptible to the flank wear as compared to the cutting speed. Flank wear increases with increase in feed rate because increasing the cutting speed and feed rate causes softening of the tool material and the diffusion where occurs the tool and the work piece. The cutting and feed forces are mostly influenced by the feed rate rather than by the cutting speed and depth of cut. Feed rate is as important as cutting speed when the tool life and the material removal rate are the vital factors to be considered when machining the metal matrix composite material.

3.3 Depth of cut (t)

The depth of cut shows less influence than the feed rate on tool wear. If the depth of cut is increased, the area of the chip-tool contact increases roughly in equal proportion to the change in depth of cut. It is evident that the depth of cut is more significant for tool wear compared to the feed rate. Experimental results shown that cutting forces increase with increase in the depth of cut because of significant tool wear and also due to increase in the requirement of force for cutting increased number of particulates in the composites, encountering the tool.

Figure 8 shows the effect and results of depth of cut on feed force while machining ZA-27 alloy with garnet reinforced composite material. Figure 9 shows the effect and results of depth of cut on cutting force while machining ZA-27 alloy with garnet reinforced composite material. Figure 10 shows the effect and results of depth of cut on thrust force while machining ZA-27 alloy with garnet reinforced composite material. Figure 11 shows the effect of cutting speed, feed rate and depth of cut on tool wear while machining ZA-27 alloy with various percentage of garnet reinforced composite material.

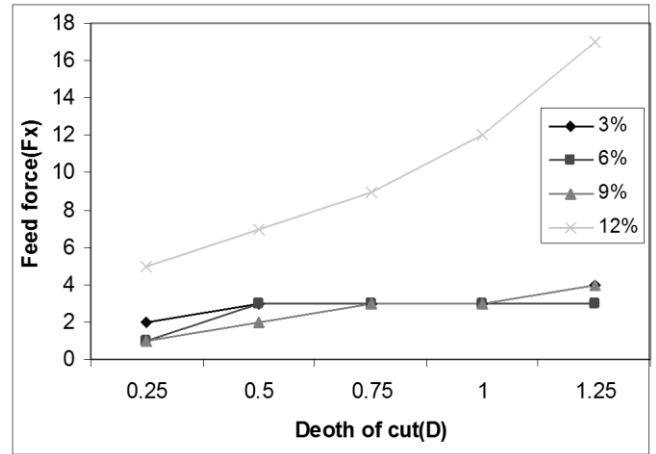


Figure 8: Effect of depth of cut and feed force while machining ZA-27 composite material.

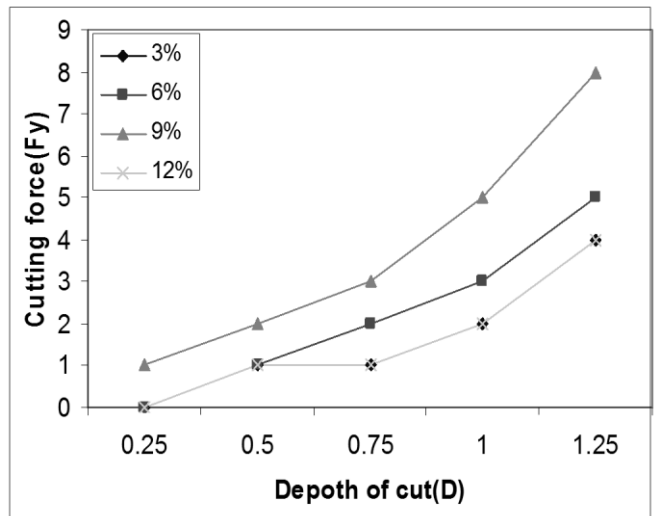


Figure 9: Effect of depth of cut and cutting force while machining ZA-27 composite material.

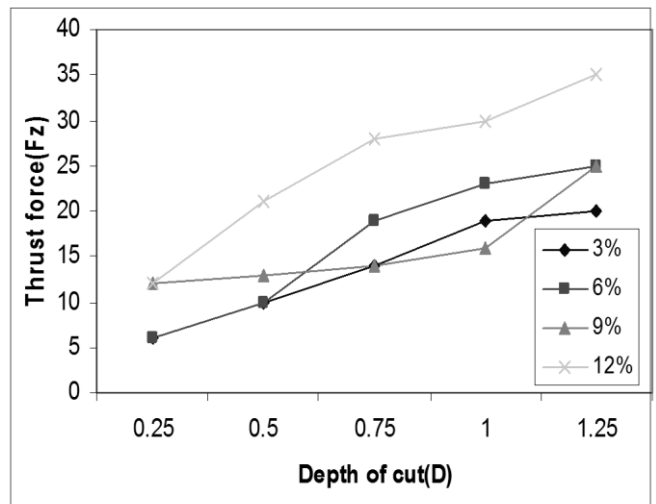


Figure 10: Effect of depth of cut and thrust force while machining ZA-27 composite material.

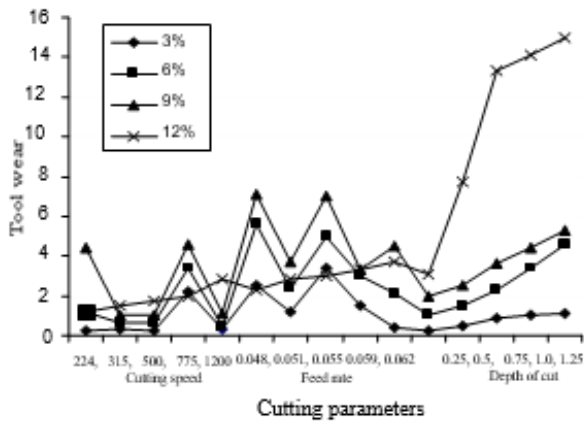


Figure 11: Effect of tool wear with percentage of reinforcement.

4. Conclusions

The following conclusions can be drawn from the present investigation on turning of ZA-27/garnet/graphite particle reinforced composites using carbide tool at different cutting parameters.

1. Feed rate is the main factor, which is influencing on the cutting forces.
2. The tool wear increases with increase in cutting speed but decreases with increase in feed rate for the composites.
3. It has been shown that tool life can be improved significantly for turning operation by operating at high speed and low feed rate and depth of cut.

Increase in the percentage of graphite reinforcement increases the tool wear. It also increases the feed and cutting forces and decreases the thrust force.

Authors' contributions

All authors contributed equally to the conception, design, experimental work, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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