Analysis of Power Consumption in the drilling of Nano SiC reinforced Aluminium matrix composites

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Abstract. Nanoceramic particles reinforced Metal Matrix Composites (MMNC) have gained immense attention from both the scientific and industrial community. The employment of these advanced class materials in the industries has given many advantages. These Nanocomposites are very difficult to machine, and the number of holes is to be drilled on their surface for many applications as drilling is considered as one of the significant applications in the industry. The researchers and industrial experts are striving very hard to attain green manufacturing techniques in drilling, which creates less impact on the environment and consume lower power. The main aim of current research is to analyse the power consumption in the drilling of Nano silicon carbide (SiC) reinforced Aluminium (Al) matrix composite under various machining conditions, cutting speeds, feed rates. For this purpose, a series of experiments have been planned using Taguchi’s L18 orthogonal array. The drilling tests were performed using a vertical machining centre (VMC) which is controlled by computer numeric control (CNC) employing carbide drills of 10mm dia with cutting point angles of 90\(^o\), 118\(^o\) and 135\(^o\). The machining operation is performed under Dry cutting and Cryogenic cutting condition. On successful completion of the experiments, the surface morphology is studied using Field Emission Scanning Electron Microscopy (FESEM).

Key Words: Nano SiC particles; Drilling; Cryogenic; LN\(_2\); Taguchi L18 array; FESEM.

1. Introduction

The Metal Matrix Nano Composites (MMNCs) are remarkably focused over the recent years mostly due to their wider functional, structural characteristics and their applications [1]. These advanced class of materials own superior mechanical strength, and best distortion resistance, the product manufacturing with these materials remain a significant challenge for the industrial sector [2]. Henceforth, various researchers had been conducted on the viability study of green manufacturing of MMNCs, to reduce the undesirable influence of machining on the environment, and also to reduce the power consumption in the machining of these advanced class of materials [3]. Many researchers have studied the fabrication of Nano SiC composites using stir casting process, and these composites are fabricated using Al as matrix materials and Nano SiC as the reinforcing material. The ceramic Nano SiC helped in improving the hardness, yield strength and ultimate tensile strength of the composites.
Suresh et al. had investigated the influence of nanoparticles in the Aluminium matrix composites fabricated using stir casting furnace. The authors had concluded that the inclusion of nanoparticles had produced products superior to the base material in terms of hardness and tensile strength. Thakre et al. has carried research in the burr height produced in the drilling of Al- SiC composites. The researchers have employed RSM based BBD to analyse the burr pattern. Rajmohan et al. had researched Aluminium (Al) based composites and had employed Taguchi design to analyse the drilling characteristics of the Al matrix composites. Suresh et al. had studied the turning performance of Al-based hybrid matrix composites. The experiments are planned using Taguchi L27 orthogonal array, and the optimisation of the experimental results are carried out using Grey Fuzzy algorithm. Sahu et al. had investigated the machining performance of Al-TiC matrix composites. The authors had planned the experiments using the Taguchi l16 orthogonal array and had optimised the machining performance using the multiobjective optimisation.

Wang et al. have proposed a model for energy consumption in the drilling process, authors have proposed the model based on equation consisting idle power which is calculated based on the spindle speed, the cutting power, calculated from the cutting force. Franco et al. had focused their research in the analysis of energy consumption in the micro drilling using EDM and ultrashort pulse laser machining. Rajemi et al. developed a methodology of optimisation by analysing energy use in turning operations for a machined product. Pervaiz et al. had studied the surface roughness and energy consumption in performing drilling on Al 6061. Authors had found the power consumption using power logger and had analysed the energy consumption in the drilling.

An extensive and comprehensive review of recent articles exposes that not much effort has been shown towards investigating the power consumption in the drilling of Nano SiC-Al composites. This investigation presents the experimental results and its power consumption with Dry machining and Cryogenic drilling. The drilling tests are conducted on VMC as per Taguchi L18 orthogonal array. Scanning electron microscope (SEM) was utilised for inspecting the subsurface morphology of the machined specimen.

2. Materials and Methods

In the current investigation, the materials utilised are shown in table 1.

| Sl.no | Material                  | Size       | Supplier                                      | Purity |
|-------|---------------------------|------------|-----------------------------------------------|--------|
| 1     | Aluminium                 | Billet     | M/s Micro Fine chemicals, India               | 99.99% |
| 2     | Nano SiC                  | 50-80 nm   | M/S US Research Nanomaterials Inc.            | 99%    |
| 3     | Cryogenic lubricant (LN₂) |            | M/s Cryo air products Chennai, India          | 99%    |

The MMNC of Nano SiC reinforced Al matrix composites are fabricated using ultrasonic-assisted stir casting furnace. The specimen is fabricated in the form of rectangular blocks of 150x100x100 mm. Nano SiC reinforced Al matrix composites are examined with metallographically to confirm the presence of nanoparticles using FESEM and is presented in figure 1.
Figure 1 Microstructure of Fabricated specimen

The metallographical examination provides the confirmation of the inclusion of nano SiC particles in the fabricated specimen.

2.1 Experimental details

The experiments are conducted using a CNC assisted Vertical Machining Centre (VMC) of ‘ARIX Machines Co. Ltd’ Dynamometer of ‘Kistler’ make is attached to the VMC to record the variations in Torque produced while machining. Carbide drills of 10 mm diameter with different point angles (90°, 118°, 135°) are employed for the drilling operation.

For the current research, the experiments are planned using Taguchi L18 orthogonal array and the parameters opted are Spindle Speed, Feed rate, Cooling condition, Wt% of Nano SiC. The parameters opted for the machining are shown in Table 2. The outputs considered here is Torque

Table 2 Drilling Parameters and their levels

| Sl.no | Parameters            | Notation | Units | Levels |
|-------|-----------------------|----------|-------|--------|
| 1     | Speed of Spindle      | N        | rpm   | 500    |
|       |                       |          |       | 1000   |
|       |                       |          |       | 1500   |
| 2     | Feed rate             | f        | mm/min| 50     |
|       |                       |          |       | 100    |
|       |                       |          |       | 150    |
| 3     | Point angle           | Ø        | Degree| 90     |
|       |                       |          |       | 118    |
|       |                       |          |       | 135    |
| 4     | Wt% of Sic            | w        | %     | 1      |
|       |                       |          |       | 2      |
|       |                       |          |       | 3      |
| 5     | Type of Cooling       |          |       | Dry    |
|       |                       |          |       | Cryogenic |

Machining is carried out in varying lubricative conditions which are Dry Machining (DM), and Cryogenic Machining (CM). In DM the heat generated is allowed to reduce under the atmospheric conditions, and in CM a cryogenic system has been employed to supply the LN2 on the machining zone with a delivery pressure of 3 bar [16]. The experimental layout is provided in figure 2.
The experimental design and the results of the experimentation are provided in table 3. The power has been calculated from the torque generated in the experimental procedure. The equation 1 is used for the calculation of power consumption and is provided

\[ power = \frac{2\pi NT}{60} \]  

Equation 1 for calculating power

Where,

- N= Spindle speed (rpm)
- T= Torque (N-m)
Table 3 Experimental design

| Sl. No | Cooling Condition | Spindle speed (rpm) | Feed Rate (mm/min) | Wt% of SiC | Point angle | Torque (N-m) | Power (w) |
|--------|-------------------|---------------------|--------------------|------------|-------------|--------------|-----------|
| 1      | Dry               | 500                 | 50                 | 1          | 90          | 1.773        | 92.79     |
| 2      | Dry               | 500                 | 100                | 2          | 118         | 1.192        | 62.38     |
| 3      | Dry               | 500                 | 150                | 3          | 135         | 1.707        | 89.33     |
| 4      | Dry               | 1000                | 50                 | 1          | 90          | 1.046        | 109.48    |
| 5      | Dry               | 1000                | 100                | 2          | 118         | 1.453        | 152.08    |
| 6      | Dry               | 1000                | 150                | 3          | 135         | 1.987        | 207.97    |
| 7      | Dry               | 1500                | 50                 | 2          | 118         | 1.446        | 227.02    |
| 8      | Dry               | 1500                | 100                | 3          | 135         | 1.508        | 236.76    |
| 9      | Dry               | 1500                | 150                | 1          | 90          | 1.796        | 281.97    |
| 10     | Cryogenic         | 500                 | 50                 | 3          | 135         | 1.584        | 82.90     |
| 11     | Cryogenic         | 500                 | 100                | 1          | 90          | 1.829        | 95.72     |
| 12     | Cryogenic         | 500                 | 150                | 2          | 118         | 1.309        | 68.50     |
| 13     | Cryogenic         | 1000                | 50                 | 2          | 118         | 1.364        | 142.77    |
| 14     | Cryogenic         | 1000                | 100                | 3          | 135         | 1.905        | 199.39    |
| 15     | Cryogenic         | 1000                | 150                | 1          | 90          | 1.938        | 202.84    |
| 16     | Cryogenic         | 1500                | 50                 | 3          | 135         | 1.18         | 185.26    |
| 17     | Cryogenic         | 1500                | 100                | 1          | 90          | 1.785        | 280.25    |
| 18     | Cryogenic         | 1500                | 150                | 2          | 118         | 1.905        | 299.09    |

3. Results and Discussion

3.1 Effect of Spindle speed on power consumption

The variations recorded are analysed and provided in figure 3. The results illustrate that the power consumption tends to increase from 81.33w to 248.7w as the spindle speed increases from 500rpm to 1500 rpm in the case of DM and the in the contrary the power consumption is found to increment from 82.4w to 254.9w as the spindle speed increases from 500rpm to 1500 rpm in CM. This raise in the power consumption is majorly due to the strain hardening of the material in the case CM.
3.2 Effect of Feed rate on power consumption

The variations recorded are provided in figure 4. The results indicate that the power consumption tends to increase from 143.1W to 193.09W as the spindle speed increases from 50 mm/min to 1500 mm/min in the case of DM and the, on the contrary, the power consumption is found to increment from 136.9 W to 190.1W as the spindle speed increases from 500rpm to 1500 rpm in CM. From the observation, it is found that as the feed rate increases the power consumption also increases, this is majorly due to the development of thrust forces at higher feeds which results in higher power consumption.
3.3 Effect of wt% of Nano SiC on power consumption

The variations in power consumption are recorded, and analysed is provided in figure 5. The results illustrate that the power consumption tends to follow a typical structure which shows that the power consumption had reduced from 161.14 w to 147.16 w when the wt % of Nano SiC increased from 1% to 2% in DM and the power consumption had increased from 147.16 w to 177.97 w when the wt % of Nano SiC increased from 2% to 3% in DM. The CM has followed a decrement of power consumption in the whole cycle as the wt % of Nano SiC increased from 1% to 3% the power consumption found to be reduced from 192.29 w to 155.85 w.

![Figure 5 Effect of Nano SiC wt % on Power consumption](image)

3.4 Effect of cooling condition on power consumption

The variations in the experimental procedure are recorded and are provided in figure 6. The results illustrate that the power consumption is found to be higher in CM when compared with DM. The results indicate that the power consumption of DM is 162.9 w and the power consumption in the CM is 172 w. The power consumption in the CM is found to be high due to the employment of Cryogenic LN$_2$ as the material gets hard when cooled rapidly.

![Figure 6 Effect of Cooling Condition on Power consumption](image)
3.5 Analysis of Machined Surface

The machined Nano SiC reinforced Al matrix composites is examined for the microstructural changes employing FESEM. The micrographic studies indicate that Nano SiC is found to be evenly distributed in the material. The FESEM micrographs are presented in the figures 7-12. These micrographs of the Nano SiC reinforced Al matrix composites indicates the presence of voids, continuous and discontinues tracks; adhered debris, craters in the machined zone. When the drilling process starts, the drill bit tends to crush the workpiece, causing surface tearing. These tracks were formed because of the strain hardening of the specimen. It can be concluded that the utilisation of cryogenic LN2 in the experimentation generates better surface finish and also helps in increasing the tool life [16].

![Figure 7(a) Dry drilling at Spindle speed = 1500, Feed rate = 150mm/min, Point angle = 90, Wt= 1%](image1)

![Figure 7(b) Cryogenic drilling at Spindle speed = 1500, Feed rate = 150mm/min, Point angle = 90, Wt= 1%](image2)

Figure 7(a) Dry drilling at Spindle speed = 1500, Feed rate = 150mm/min, Point angle = 90, Wt= 1%

Figure 7(b) Cryogenic drilling at Spindle speed = 1500, Feed rate = 150mm/min, Point angle = 90, Wt= 1%

![Figure 8(a) Dry drilling at Speed of Spindle = 500, Feed rate = 100mm/min, Point angle = 118, Wt= 2%](image3)

![Figure 8(b) Cryogenic drilling at Spindle speed = 500, Feed rate = 100mm/min, Point angle = 118, Wt= 2%](image4)

Figure 8(a) Dry drilling at Speed of Spindle = 500, Feed rate = 100mm/min, Point angle = 118, Wt= 2%

Figure 8(b) Cryogenic drilling at Spindle speed = 500, Feed rate = 100mm/min, Point angle = 118, Wt= 2%
4. Conclusions

- In this paper, an analysis for power consumption in the drilling of Nano SiC reinforced Al matrix composites had been carried basing upon the spindle speed utilised in the experimental procedure and the Torque generated while machining.
- The power consumed for the machining process was found using an empirical calculation.
- Higher feeds tend to consume higher power.
- Employment of cryogenic LN$_2$ consumes higher power in drilling, which is mainly due to the hardening of materials at low temperatures.
- The application of advanced cryogenic LN$_2$ helped in providing a better surface finish.
- It is also observed that the tool life has also increased by employing cryogenic LN$_2$.
- FESEM metallographic studies indicate the distribution of Nano SiC particles evenly in the composite
- The metallographic studies indicate that the formation of cracks on the surface of composite, which are majorly due to the strain hardening of the material.

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