Study of the G-ratio of aluminium silicon carbide nano particles reinforced metal matrix composites

A.Nandakumar1 T. Rajmohan2 R.Sundararajan3 K.Venkatesh4 N.Muni Deepak5 K.Venkateshwaran6

Department of Mechanical Engineering, Sri Chandrasekharendra Saraswathi Viswa Maha Vidyalaya University, Enathur, Kanchipuram – 631561, India

E-mail: 1nandakumar.a@kanchiuniv.ac.in and 2rajmohanscsvmv@yahoo.com

Abstract: Grinding plays an essential role in obtaining high dimensional accuracy and surface finish. Three types of work pieces were used with different ratios of SiC (1%,2%,3%). When the composition of SiC increases, the G-ratio decreases. This type of material is highly used in aerospace applications due to its low density and good wear and corrosion resistance. It is genuinely believed that Al-SiC has tremendous potential for application in the aerospace industry. A critical role is played by grinding in achieving good surface finish and improved dimensional accuracy. Therefore, a strategy to improve the grinding rate and surface finish is important for economic production. In this research, the various grinding ratio was found out and results show that G-ratio is high when coolant is used and G-ratio is low when coolant is not used.

Key words: Grinding; Nano TiO2; Nano SiC particles; G Ratio

1. Introduction

Composites are materials in which two phases are combined, usually with strong interfaces between them. They usually consist of a continuous phase called the matrix and discontinuous phase in the form of fibers, whiskers or particles called the reinforcement. Considerable interest in composites has been generated in the past because many of their properties can be described by a combination of the individual properties of the constituent phases and the volume fraction in the mixture. Composite materials are gaining wide spread acceptance due to their characteristics of behavior with their high strength to weight ratio [1]. Metal Matrix Nano Composites (MMNCs) are being used increasingly in both the aeronautical and automotive industries [2]. The successful and cost-effective machining of MMCs is essential in order to get defect free components having a required dimension and improved surface finish. The grinding operation might participate a significant role for finishing and durable machining, where a single grinding process symbolizes a cost-effective choice, as it removes require for prior conventional machining process [3]. Numerous ceramic reinforcements are recognized for MMCs, but Silicon carbide (SiC) has expanded interest due to its high rigidity, high specific strength, solidity, wear resistance and dimensional strength [4].
The machining of SiC reinforced composites presents significant challenges to industries due to the high abrasiveness of the reinforcing particles and the anisotropic & non homogenous structure. Precipitate collapse of tool is accounted as the main difficulty in machining of MMC [5]. It is significant to extend quantitative analytical models for sustainable manufacturing and product design in order to appreciate the vital role of the components of sustainability in manufacturing of products [6]. Increasing quantities of metal matrix composites (MMCs) are being used to replace conventional materials in many applications, especially in the automobile and recreational industries, owing to increasing performance requirements [7]. The most popular types of MMCs are aluminium alloys reinforced with ceramic particles. These low-cost composites provide higher strength, stiffness and fatigue resistance [8], with a minimal increase in density over the base alloy. The superior mechanical properties achieved by the reinforcements in MMCs, on the other hand, significantly influence their “machinability” [9]. This term which describes the operational characteristics of a cutting tool in machining a material is rather ill-defined and is normally judged in terms of tool life, surface finish and power required for material removal [10].

Aluminium-based metal matrix composites (MMCs) reinforced with ceramic particles are advanced materials known for their good damping properties, high specific strength, and high wear resistance [11]. Methods to produce these composites and studies on their mechanical properties have gained popularity. MMCs are increasingly used in astronomic, automobile, and military industries [12]. In addition, the sporting goods industry has also been in the forefront of MMCs development capitalizing on the materials’ high specific properties [13]. Reports on machining of Aluminium-based MMCs reinforced with ceramic particles [14] are still scarce. Despite many advantages, full implementation of MMCs is cost-prohibitive. This is partially due to the poor machinability of the materials. Although near-net-shape MMC components can be produced, final finishing is still required for obtaining designed final dimensions and required surface finish [15].

Significant cost and fabrication problems, including machining, must be overcome for the successful application of these composites. Surface finish and surface integrity are important for surface sensitive parts subjected to fatigue. Subsurface damage due to the machining of MMCs results from conventional and unconventional processes, therefore, finishing processes such as grinding are used to improve the surface integrity of machined MMCs [16]. The objective of this paper is to study the G ratio of aluminium silicon carbide nano particles reinforced metal matrix composites. Grinding plays an essential role in obtaining high dimensional accuracy and surface finish. Three types of workpieces were used with different ratios of SiC (1%, 2%, 3%). This type of material is highly used in aerospace applications due to its low density and good wear and corrosion resistance.

2. Materials and Methods

Aluminium billet obtained from M/s Micro Fine chemicals, India. and SiC Nanoparticles procured from M/S US Research Nanomaterials Inc, USA are employed as base material for synthesizing the Nanocomposites. Aluminium reinforced with SiC Nanoparticles are fabricated by Vacuum based solidification processing [17]. SAE20W40, Cashew nut-based vegetable oil and Nano TiO$_2$ were procured from M/s Ganapathy traders, India. The average diameter and length of the Nano tubes vary from 10-20 nm and 10-30 µm respectively and Nano TiO$_2$ were mixed with Cashew nut-based vegetable oil using ultrasonic processor.
The preparation of the Nano fluids includes dispersion of 10 gm of Nano TiO$_2$ in 500 ml of vegetable oil-based fluid. The processed samples were kept ideal for 24 hours earlier to the property measurements. The Scanning Electron Microscopy (SEM) (Quanta FEG 200, Japan) analysis was hired for defining the size and morphology of the nanoparticles. It is clear from the Figure 1 that morphology of nanoparticles is nearly spherical in shape and it is also confirmed that the sizes of the dispersed nanoparticles are within the specified range. The properties of NanoTiO$_2$ mixed fluids were tested and the results were presented and compared with the SAE20W40 and Cashew nutshell Oil and are presented in the Table 1.

Table 1. Rheological properties of the Lubricants

| Properties                  | SAE20W40 | Vegetable Oil (Cashew nut shell Oil) | Vegetable Oil (Cashew nut shell Oil + TiO2) |
|-----------------------------|----------|-------------------------------------|--------------------------------------------|
| Flash point (°C) [ASTM D92] | 200      | 214.27                              | 190.2                                      |
| Thermal Conductivity Watt/mK| 0.152    | 0.161                               | 0.169                                      |
| Viscosity @100°C (cSt) [ASTM D445] | 15.2 | 15.48                               | 16                                         |
| Viscosity index [ASTM D2270]| 120      | 126                                 | 158                                        |

Figure 1. SEM image of Nano TiO$_2$

From the rheological properties it is found that a considerable improvement in the properties was observed in TiO$_2$ filled cashew nut-based vegetable oil due to the enhanced heat cropping ability of Nano fluid [18]. The gravity die casting technique was used to prepare the Nano SiC reinforced Al matrix composites and microstructure of prepared samples were presented in Figure 2.
3. Experimental Work

The cylindrical grinding machine is a type of grinding machine used to shape the outside of an object. The cylindrical grinder can work on a variety of shapes; however, the object must have a central axis of rotation. This includes but is not limited to such shapes as a cylinder, an ellipse, a cam, or a crankshaft. Roughness is an important parameter when trying to find out whether a surface is suitable for a certain purpose. Rough surfaces often wear out more quickly than smoother surfaces. A roughness tester is used to quickly and accurately determine the surface texture or surface roughness of a material.

4. Results and Discussions

The Grinding experiments are carried out on a horizontal spindle cylindrical grinding machine (Type G13P, HMT make). In present study the cylindrical specimens of MMNC were ground with the selected aluminium oxide grinding wheel (AA60K5V8). The G Ratio of the experimentation is provided in the following Tables 2 and 3. The G ratio used by the operation is determines, volume of metal removed divided by volume of wear of tool.
Table 2. Grinding ratio (G-Ratio) without coolant

| % OF NANO SiC | 1%     | 2%     | 3%     |
|--------------|--------|--------|--------|
|              | Before | After  | Before | After  | Before | After  |
| WORKPIECE DIAMETER | 16.12 | 15.92  | 16.18  | 16.03  | 17.06  | 16.96  |
| WHEEL DIAMETER | 189.18 | 189.14 | 188.18 | 188.14 | 188.10 | 188.06 |
| LENGTH OF WORKPIECE | 122.18 | 136.18 | 126.18 |
| WHEEL THICKNESS | 21.04  | 21.04  | 21.04  |
| G-RATIO       | 2.45   | 2.07   | 1.35   |

Table 3. Grinding ratio (G-Ratio) with coolant

| % OF NANO SiC | 1%     | 2%     | 3%     |
|--------------|--------|--------|--------|
|              | Before | After  | Before | After  | Before | After  |
| WORKPIECE DIAMETER | 15.92 | 15.72  | 15.98  | 15.88  | 16.86  | 16.76  |
| WHEEL DIAMETER | 188.08 | 188.06 | 188.04 | 188.02 | 188.02 | 188.00 |
| LENGTH OF WORKPIECE | 122.18 | 136.18 | 126.18 |
| WHEEL THICKNESS | 21.04  | 21.04  | 21.04  |
| G-RATIO       | 4.88   | 2.74   | 2.68   |

4.1 Analysis of Grinding Ratio

The bar chart describes the variation of G-Ratio with and without coolant is shown in Figure 3. Y-axis represents the grinding ratio and X-axis represents the percentage of Nano SiC in Al. The G ratio gradually decreases when there is an increase in the percentage of Nano SiC. There is a sharp drop in G-Ratio between 1% and 2% and a slight drop between 2% and 3% when no coolant is used. The G Ratio is less all conditions of MMNC for providing coolant in grinding operations.
5. Conclusions

Based on the results of the present experimental investigation, the following conclusions for MQL grinding of MMNC can be drawn.

- The large apertures are a feature of good cutting capability and show that Nano fluids are reserved on the grinding wheel surface. The fissure networks on the grinding wheel are like micro-reservoirs that can accumulate Nano fluids for the time being. This property guarantees that micro-reservoirs can carry TiO$_2$ Nano particles into the grinding zone.

- Nano fluids on abrasive grain surfaces can form a layer of TiO$_2$ Nano fluid lubricating film through physical and chemical reactions; this layer can inhibit the generation of wear flats and cause them to fall off of the abrasive grains effectively.

- The TiO$_2$ nano particles with a nano size and spherical appearance serve as good “bearings” in the grinding Zone.

- TiO$_2$ nano particles prevent direct contact in the friction pair, change the sliding friction between the abrasive grains and the workpiece into rolling friction, and reduce the wear flats of grains by narrowing the contact area between them and the workpiece.

- The G-Ratio gradually decreases when there is an increase in the percentage of Nano SiC. There is a sharp drop in G-Ratio between 1% and 2% and a slight drop between 2% and 3% when no coolant is used.

- The G-Ratio is less for all conditions of MMNC for providing coolant in grinding operations.

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