

Tool Wear of Metal Matrix Composite 10wt% AlN Reinforcement Using TiB₂ Cutting Tool

M. S. Said, J. A. Ghani, Che Hassan C. H., N. N. Wan, M. A. Selamat, R. Othman

Abstract—Metal matrix composites (MMCs) attract considerable attention as a result from its ability in providing a high strength, high modulus, high toughness, high impact properties, improving wear resistance and providing good corrosion resistance compared to unreinforced alloy. Aluminium Silicon (Al/Si) alloy MMC has been widely used in various industrial sectors such as in transportation, domestic equipment, aerospace, military, construction, etc. Aluminium silicon alloy is an MMC that had been reinforced with aluminium nitride (AlN) particle and become a new generation material use in automotive and aerospace sector. The AlN is one of the advance material that have a bright prospect in future since it has features such as lightweight, high strength, high hardness and stiffness quality. However, the high degree of ceramic particle reinforcement and the irregular nature of the particles along the matrix material that contribute to its low density is the main problem which leads to difficulties in machining process. This paper examined the tool wear when milling AlSi/AlN Metal Matrix Composite using a TiB₂ (Titanium diboride) coated carbide cutting tool. The volume of the AlN reinforced particle was 10% and milling process was carried out under dry cutting condition. The TiB₂ coated carbide insert parameters used were at the cutting speed of (230, 300 and 370m/min, feed rate of 0.8, Depth of Cut (DoC) at 0.4mm). The Sometech SV-35 video microscope system used to quantify of the tool wear. The result shown that tool life span increasing with the cutting speeds at (370m/min, feed rate of 0.8mm/tooth and DoC at 0.4mm) which constituted an optimum condition for longer tool life lasted until 123.2 mins. Meanwhile, at medium cutting speed which at 300m/m, feed rate of 0.8mm/tooth and depth of cut at 0.4mm we found that tool life span lasted until 119.86 mins while at low cutting speed it lasted in 119.66 mins. High cutting speed will give the best parameter in cutting AlSi/AlN MMCs material. The result will help manufacturers in machining process of AlSi/AlN MMCs materials.

Keywords—AlSi/AlN Metal Matrix Composite milling process, tool wear, TiB₂ coated cemented carbide tool.

I. INTRODUCTION

METAL Matrix Composites (MMCs) have attracted considerable attention as a result of their ability to provide high strength, high modulus, high toughness, high

impact properties, improved wear resistance and better corrosion resistance than unreinforced alloy [1]. The demand for the metal matrix composite (MMC) increased from 4.1 million kilograms of materials in 2007 to 4.4 million kilograms in 2008 and is expected to increase further to 5.9 million in 2013, with the compound annual growth rate (CAGR) of 5.9%. It is reflected by the increase in numbers for ground transportation, thermal management and aerospace due to the applications of MMCs [2] engineering applications such as cylinder block linear, vehicle drive shaft, automotive piston, bicycle frame etc. [1], [3], [4]. High hardness aluminium oxide (Al₂O₃) or silicon carbide (SiC) particle is commonly used to reinforce aluminium alloys, but the full application of such MMCs is, however, cost-sensitive because of the high machining cost [5]. The long life of cutting tools will produce a lot of output and also reduce manufacturing costs [6]. In general, MMCs consist of two materials which are chemically and physically distinctive, and yet are suitably distributed to provide properties not obtainable with any of the individual phase- fibrous or particulate phase in the form of continuous, discontinuous fiber, whiskers, particles, distributed in a metallic matrix which includes light metal such as aluminum, magnesium, titanium, copper and their alloy [7], [8]. The main attractive features of the MMCs are high strength to weight ratio, excellent mechanical and thermal properties over the conventional material and alloy, improved fatigue and creep characteristics, and better wear resistance [8], [9].

As good matrix should process the ability to deform easily under the applied load, transfer the load onto the fibers and evenly distribute stress concentrations [8], [10]. Aluminum alloy reinforced with alumina and silicon carbide, as well as its reinforcement with aluminium nitride (Al/AlN) has been extensively investigated by the scientific community, as their integration shows some excellent mechanical properties and thermal properties [11]. Studies on AlN are still far from widespread, and most are confined to the production of AlN [12], [13], the study of the physical properties [14] and their use, and the manufacturing of thin film electronic materials [15]. As the manufacture and production of composite materials using casting methods such as stir have yet to be done, producing new material Al-Si/AlN MMC stirs casting method has become our focus.

Although a variety of reports on the use of AlN as the reinforcement for Al alloy composites had been published, there is evidence of the lack of knowledge concerning the characteristics of these new materials, especially the surface roughness and performance tool [16]. The reason for this is the presence of hard Al₂O₃ particle in aluminium matrix [1].

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Issues like material fabrication or machinability and the development of these materials still remain to be some unresolved dilemma to the manufacturers. Many of them claim that MMCs are harder and stiffer than the conventional materials, further leading to the cutting tool being easy to break and wear out [16]. Tool wear in machining is defined as the moment of volume loss of tool material on the contact surface, due to the interaction between the tool and work piece. Tool wear is the most critical quality measurement in many mechanical products. Among the different forms of tool wear, flank wear is a significant measure because it affects the dimensional tolerance of the workpiece [17]. The measurement of tool wear is based on the ISO 8688-2 criteria for milling machine tool life which is 0.3mm flank wear (VB).

On the other hand, dry machining is becoming important due to the awareness towards the environment and workers' health. Cutting fluid also adds another 16-20% of the manufacturing cost [18], [19] and associated cost with the cutting fluid, which sometimes exceeds the cost of labor and tooling [18]–[20]. Carbide tool is important in its machining applications due to its availability and low cost as compared to other cutting tool materials such as the CBN [18]. TiB₂ is a relatively new coating material used in carbide cutting tool inserts and is useful, owing to its high hardness and chemical inertness [21]. Ti-based hard coating is widely used in tools, dies and mechanical parts to enhance their lifetime and performance due to its attractive properties such as high hardness, high wear resistance and chemical stability [22]. This paper will present the machining factor affecting the machinability of 10wt% AlN reinforced with the AlSi alloy machined by the end milling process, and using TiB₂ coated cemented carbide of the cutting insert. The machining characterization is evaluated in terms of the flank wear of the cutting tool.

II. EXPERIMENTAL PROCEDURE

Materials and Milling Process

In the Al-SiC MMC, the composition of the matrix of the MMC is experimentally found to contain 11.1% Si, and 0.02% Zn apart from traces of other elements. The chemical composition of this AlSi alloy is shown in Table I. The reinforcement is a particulate of Aluminium Nitride with the grain size ranging <10 μm and with the purity of >98%, and is fabricated using the stir casting method. To increase the mechanical properties of this Al-SiC MMC, heat treatment was conducted. Table II shows the mechanical properties of material AlSi/AlN 10wt% MMC.

Fig. 1 shows the procedure of fabrication the metal matrix composites in laboratory. The experimental study was carried out on a CNC Vertical Milling Center Lagun-GVC1000 milling machine. Cutting inserts were attached to the tool with a body diameter of Ø20mm. The tool holder used to be KENNAMETAL 90Deg cutter holder with a commercial tool insert, grade KC410M PVD TiB₂ coating. The experiment has three different cutting speeds (230, 300 and 370 m/min) with constant feed rate (0.8 mm/tooth) and constant depth of cut

(0.4mm) under dry cutting condition. The worked material was fabricated in the form of block 120mm length x 50mm width x 50mm thickness.



Fig. 1 Fabrication of metal matrix composite was using the stir casting technique. The stir casting equipment was built in-house

Fig. 2 shows the experimental setup for measuring the tool wear until the tool life fulfills the tool life criteria of VB_{max} = 0.3 mm. The wear on the flank wear face was observed and measured using a Sometech SV-35 video microscope.

TABLE I
CHEMICAL COMPOSITION OF ALSI ALLOY

| Elements | Fe | Si | Zn | Mg | Cu | Ni |
|----------|-------|-------|--------|-------|---------|-------|
| Wt% | 0.42 | 11.1 | 0.02 | 0.01 | 0.02 | 0.001 |
| Elements | Sn | Co | Ti | Cr | Al | |
| Wt% | 0.016 | 0.004 | 0.0085 | 0.008 | Balance | |

TABLE II
MECHANICAL PROPERTIES

| AlN(%) | Hardness (Hv) | Tensile Stress (Mpa) | Ductility (%) |
|--------|---------------|----------------------|---------------|
| 10 | 137 | 146±8 | 6.2 |

TABLE III
GEOMETRY CARBIDE TOOLS USED FOR THE END MILLING OF THE TiB₂ INSERT

| ISO catalog number | Grade | L1 | W | S | L10 | BS | Rε |
|--------------------|--------|----|-----|-----|-----|----|-----|
| ADKT103504PDFRLC | KC410M | 10 | 6.7 | 3.5 | 10 | 2 | 0.4 |

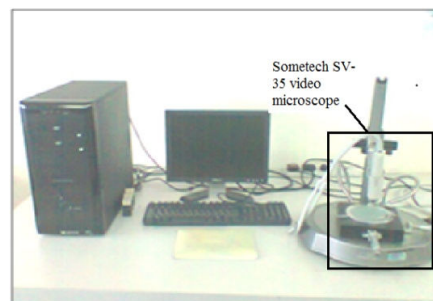


Fig. 2 Experimental setup for measuring tool wears in the milling process

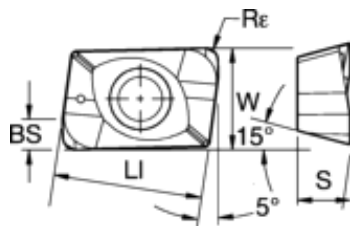


Fig. 3 Illustration of the geometry of the cutting tool

The tool geometry of TiB₂ insert is shown in Table III while Fig. 3 shows the illustration tool and the cutting insert. Before the cutting process is done, all cutting tools are observed using an optical microscope to see if the cutting tool is damaged. If there is damaged, then it cannot be used for experiments.

III. RESULT AND DISCUSSION

As stated in many previous findings, another primary objective of the long life of cutting tools is also concerned over the quality of the material of the components produced [23], [24]. The results have revealed that the tool wear increases with the cutting speed (370 m/min, feed rate 0.8 mm/tooth and depth of cut 0.4mm) which constituted an optimum condition for longer tool life which is 123.2 min.

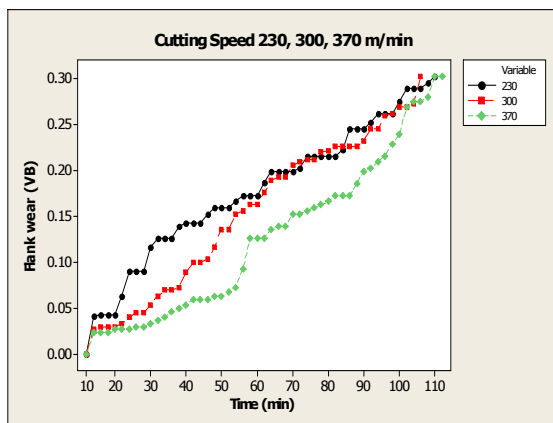


Fig. 4 Flank Wear (Vb Max) Vs. Machining Time (Min)

Meanwhile, at medium cutting speed, it is found that the cutting speed of 300m/min, feed rate 0.8 mm/tooth and depth of cut 0.4mm give only 119.86 min for tool wear mean while lower cutting speed gives 119.66 min. The highest cutting speed gives the best parameter for cutting AISi/AIN MMCs materials.

The long life of cutting tools will produce a lot of output and also reduce manufacturing costs. They also say that the life of cutting tools is highly dependent on cutting parameters such as cutting speed, feed rate and depth of cut [13].

For the cutting speed 300 and 230 m/min, feed rate 0.8 and the same depth of cut 0.4, the time showed not much difference. It means that the cutting speed left not much effect on the TiB₂ insert, and it may be influenced by the tool geometry. Thus, it can be said that cutting tool life is not

dependent on the cutting speed, but it depends on the feed rate, depth of cut and type of insert [6].

According to Taylor, the most effective parameters on the life of the cutting tool is the cutting speed [20], [23]. The effect of time on wear can be seen in three stages: initial, steady state and worn-out regions [17]. Fig. 4 shows the result of the flank wear of the TiB₂ coated cemented carbide.

In regard of the increased cutting speed and the results of the increased flank wear, at the initial stages shown in Fig. 4, when time reached 40 min, the cutting speed that was 370 m/min achieved VB 0.05mm, cutting speed 300 m/min achieved VB 0.10mm and when cutting speed 230 m/min it obtained VB 0.15mm. As we approached the steady state, the cutting speed 370 m/min had achieved VB 0.15mm, while cutting speed 300 and 230m/min remained to obtain VB 0.22mm at 80 min. The flank wear had a worn-out region at 120min and above. It shows that the flank wear was achieved due to ISO 8688-2. The flank wear is explained by the abrasive nature of hard Al₂O₃ particle present in the work materials [5]. When cutting MMCs with coated carbide, the coating was removed from the tools, and the dominating wear occurred on the flank face of the tool [5].

IV. CONCLUSION

The machinability of the AlN-reinforced aluminium metal matrix composite (MMC) using TiB₂ coated cemented carbide insert has been evaluated. The following observations have been made:

- The results have revealed that the tool life increases with the cutting speed (370 m/min, feed rate 0.8 mm/tooth and depth of cut 0.4mm) constituting an optimum condition for longer tool life which is 123.2 min. At medium cutting speed, it is found that the cutting speed of 300m/min, feed rate 0.8 mm/tooth and depth of cut 0.4mm give only 119.86 minutes for the tool wear mean, while lower cutting speed gives 119.66 minutes.
- Highest cutting speed gives the best parameter for cutting AISi/AIN MMCs materials.
- The result will help manufacture in the machining of the AISi/AIN MMCs materials.

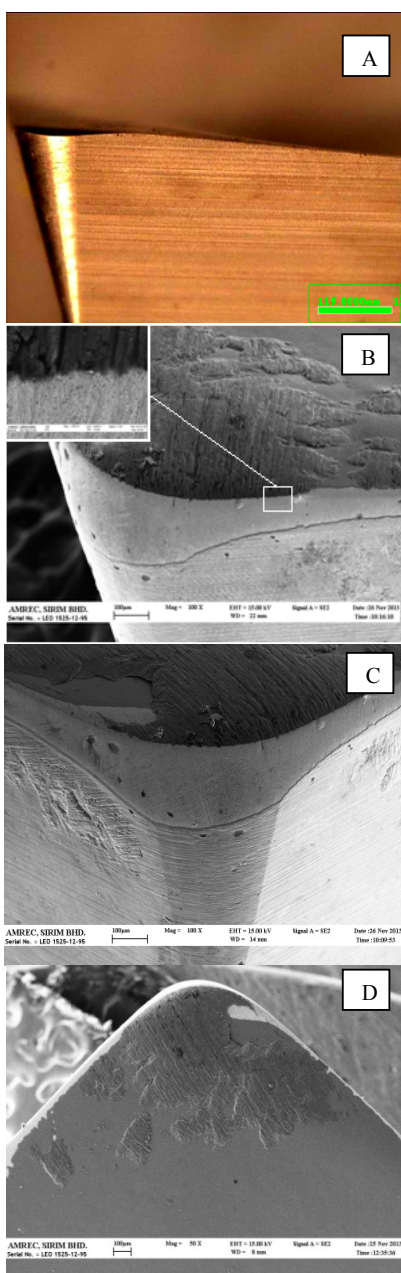


Fig. 5 Tool wear TiB_2 insert, optic (a) before cutting. it was observed using a Somotech SV-35 video microscope and SEM image of the flank view, (b) - 200 μ m, nose view, (c)-100 μ m and top view, (d) - 100 μ m, showing the deformation of wear at 123.2 min for 370 m/min cutting speed, feed rate 0.8 m/tooth and doc 0.4mm.

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