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Research Article

Chip Formation in the Machining of Al-Si/10% AlN Metal Matrix Composite by using a TiN-coated Carbide Tool

[1]M.S. Said, [2]J.A. Ghani, [2]C.H. Che Hassan, [1]J.A. Shukor, [3]M.A. Selamat and [4]R. Othman
[1]Manufacturing Section, Universiti Kuala Lumpur Malaysian Spanish Institute, 09000 Kulim Hi-Tech Park, Kulim Kedah,
[2]Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor,
[3]Structural Materials Programme, Advance Materials Research Centre (AMREC), SIRIM, Berhad, Lot 34, Jalan Hi-Tech 2/3, Kulim Hi-Tech Park, 09000 Kulim, Kedah,
[4]Mechanical Section, Universiti Kuala Lumpur Malaysian Spanish Institute, 09000 Kulim Hi-Tech Park, Kulim Kedah, Malaysia

Abstract: This paper presents a study on chip formation in the milling process of Al-Si/10% AlN Metal Matrix Composite (MMC). It focuses on the effect of cutting parameters on the formation of the chip. Al-Si/10% AlN MMC reinforced with 10% AlN particle is a new-generation material that is suitable for manufacturing automotive and aerospace components. Several advantageous characteristics of this material include low density, light weight, high strength, high hardness and high stiffness. The milling process was carried out at dry cutting conditions by using TiN-coated carbide tool insert, which was developed by Standards and Industrial Research Institute of Malaysia (SIRIM). The machining parameters were as follows: a constant cutting speed of 230 m/min, feed rates of 0.4, 0.6 and 0.8 mm/tooth and cutting depths of 0.3, 0.4 and 0.5 mm. The analysis of the chip formation was performed using a video microscope (Sometech, SV-35). The chips were formed because of the shear between the work pieces and the cutting chips during dry milling of Al-Si/10% AlN MMC. These chips were small, short and discontinuous with outer face cracks.

Keywords: Al-Si/10% AlN Metal Matrix Composite (MMC), chip formation, milling process, TiN

INTRODUCTION

AlSi alloy is a Metal Matrix Composite (MMC) that is widely used invarious industrial sectors, such as transportation, domestic equipment, aerospace, military and construction. It is a matrix composite reinforced with AlN particle and transformed into a new-generation material for automotive and aerospace applications (Said *et al*., 2014). In general, Al/Si MMCs consist of two chemically and physically distinct materials that are suitably distributed to provide properties that are not obtainable from either the individual phase or fibrous or particulate phase in the form of continuous or discontinuous fiber, whiskers and particles. They are distributed in a metallic matrix containing light metals, such as aluminum, magnesium, titanium and copper and their alloys (Said *et al*., 2014; Sahin and Sur, 2003; Patel and Patel, 2012; Chawla and Chawla, 2006). Al-Si MMCs materials have increasingly replaced conventional materials in many applications. MMC has a combination of metal and ceramic properties (Abdullah, 2009; Said *et al*., 2013). Chip formation is an important index of machining because it directly or indirectly indicates the nature and behavior of work at machining conditions as well as the nature and degree of interaction at the chip-tool interfaces (Radhika *et al*., 2013). MMC has very good mechanical properties, which are caused by the combination of hard reinforcement, such as SiC and elastic matrix material, such as aluminum or magnesium (Shetty *et al*., 2008).

To date, only a few reports exist on the use of AlN as a reinforcement to the composite Al alloy. To achieve a longer tool life in the current production practices as well as to enhance our knowledge on tools that can withstand high cutting temperatures, understanding the mechanism of chip formation is a fundamental element that influences tool performance (Said *et al*., 2014). Models are used to understand the orthogonal cutting chip formation mechanism. The formation mechanism of the pieces depends on the nature of the machined material and the machining parameters. The three types of chips produced in machining (Oxley, 1989; Said *et al*., 2014) are

Corresponding Author: M.S. Said, Manufacturing Section, Universiti Kuala Lumpur Malaysian Spanish Institute, 09000 Kulim Hi-Tech Park, Kulim Kedah, Malaysia

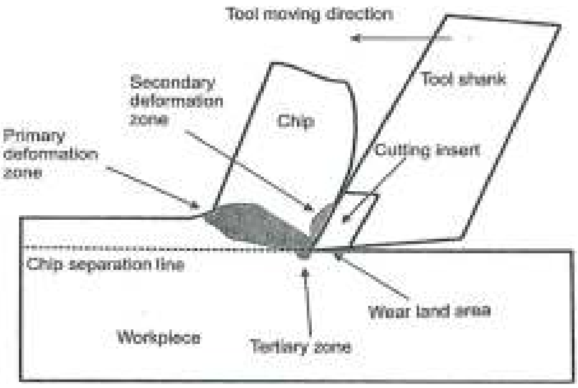

Fig. 1: Major deformation zone in metal cutting (17)

discontinuous, continuous and continuous with built-up edge. Discontinuous chips are chips formed with multiple segments and produced when machining brittle materials at a low cutting speed. Continuous chips are produced when machining ductile materials at a high cutting speed and at a low feed rate (Groover, 1996). Continuous with built-up edge chips are produced when machining ductile materials at a low cutting speed. The study of chip formation is the cheapest and most effective approach to understand the machining characteristic of a material (Radhika *et al*., 2013).

Chips produced can be divided into two categories, namely, acceptable and unacceptable chips (Ghani and Yong, 2006). Acceptable chips do not disturb work or machine tool and do not cause problems in chip removal, whereas unacceptable chips disrupt manufacturing operations because they have a tendency to shrink around tools and work piece as well as inflict security problems to workers (Ghani and Yong, 2006). Figure 1 shows the deformation zone during the machining process. A low shear zone extends along the shear plane and represents the boundary between the chip and the work piece material, which is subjected to sheared formation. The secondary shear zone is located along the tool rake surface and is subjected to additional shear to form the chip. The second area includes the interface between the chip and the tool rake face. Some of the shear caused by rubbing off or side face of the tool for the newly generated surface can also be observed.

This study presents chip formation during Al-Si/10%AlN MMC machining on different parameters of feed rate, cutting depth and constant cutting speed by using the TiN-coated insert. The factors that influence chip formation were identified and their effect on improving the machinability of new materials was proposed. Figure 1 shows the major deformation zone in metal cutting. Friction and wear characteristics of the tool or work piece combination were important in this zone.

METHODOLOGY

Experimental machining: Al-Si/10%AlN MMC was produced via the stir casting process in block form with

Fig. 2: Fabrication of metal matrix composite using the stir casting technique

a size of 120 mm long×100 mm wide ×50 mm thick. Table 1 shows its composition. The material is reinforced with 10% of small AlN particles with size of <10 µm and purity of >98%. The Al-Si/AlN MMC was fabricated via the stir casting method. The AlSi alloy ingot was heated in a graphite crucible at 750°C and held for 30 min until the material was completely melted. The preheated AlN particles were added to the molten metal, stirred for 5 min (Fig. 2) and immediately casted into a permanent mold via the bottom pour technique. The solidified Al-Si/10%AlN metal matrix composite underwent a heat treatment process to improve its mechanical properties, such as strength and hardness (Tomadi *et al*., 2013). The three stages of the heat treatments were solution treatment (0 to 540°C for 30 min and 540°C for 4 h), water quenching (60°C) and continuous aging (0 to 180°C for 30 min and 180°C for 4 h). Figure 3 shows the microstructure of Al-Si/10%AlN MMC with 10x magnification after heat treatments Table 2 shows the mechanical properties of 10 wt. % Al-Si/AlN MMC materials.

The milling process was carried out at dry cutting conditions by using the TiN-coated carbide tool insert, which was developed by SIRIM (Advance Materials Research Centre). The TiN films were deposited on the carbide insert at similar physical conditions by using

Table 1: Chemical composition of materials

Element	Fe	Si	Zn	Mg	Cu	Sn	Co	Ti	Cr	Al
wt %	0.42	11.1	0.02	0.0107	0.02	0.016	0.004	0.0085	0.008	Equilibrium

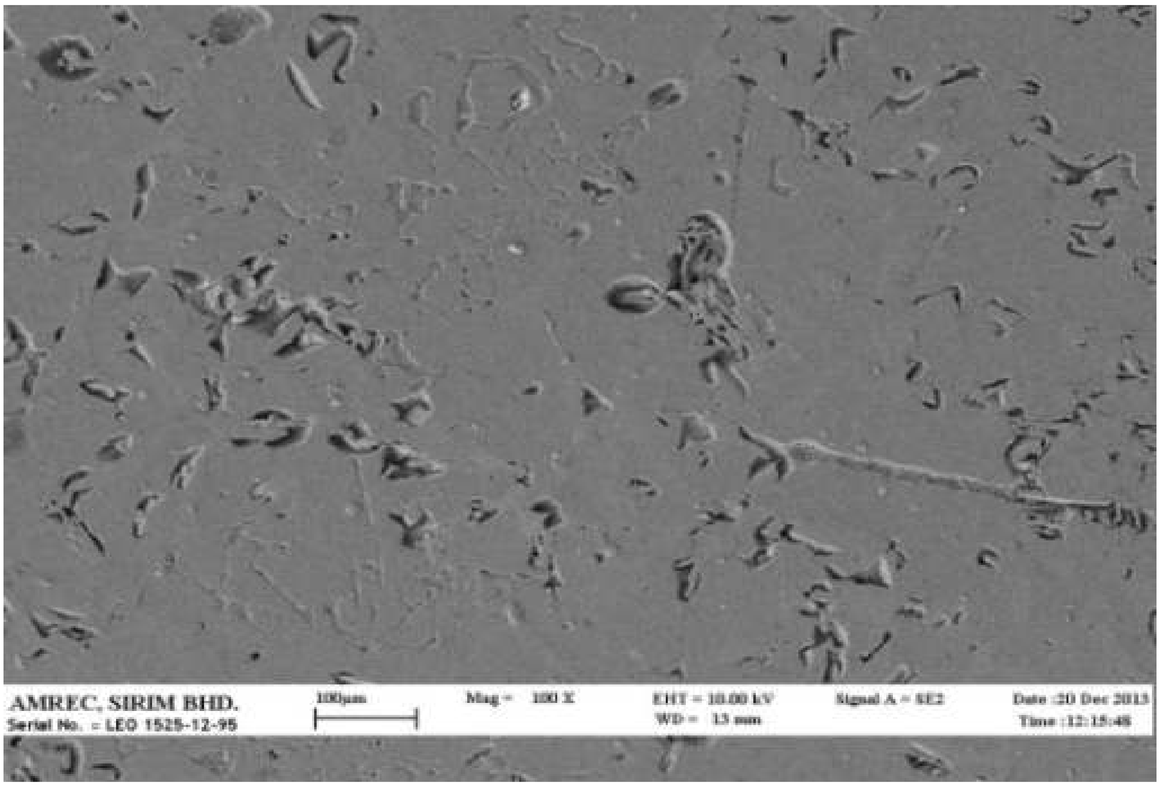

Fig. 3: Microstructure of Al-Si/10%AlN MMC with10x magnification

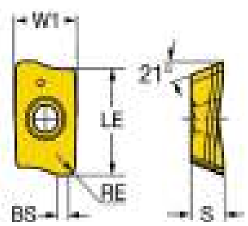

Fig. 4: Illustration of the geometry of the cutting tool

Table 2: Mechanical properties 10WT%AL-SI/ALN

Hardness (Hv)	Modulus of Elasticity (Gpa)	Tensile strength (Mpa)	Elongation (%)
110	7.0±3.5	146±8	6.2±3.5

Table 3: Deposition parameters

Rotation speed (%)	Deposition time (h)	Bias voltage (-V)	N_2 gas flow rate (sccm)
60	60	-50	250
Etching (min)	Pre-bias (V)	Substrate temperature (°C)	Coating Thickness
5	1000	300	≈4.7µm

the Hauzer Techno Coating 9HTC 625/2 ARC coating system. The substrates were cleaned for 30 min in an ultrasonic bath by using a mild, solvent-free, detergent. The substrates were blow-dried using high-pressure nitrogen gas to remove any dust contaminants from the surface and then placed into the coating chamber. Film

Table 4: Geometry carbide tools used for milling AL-SI/10%ALN MMC

Tool type	Titanium Nitride (TiN)
Manufacturer	Sandvik
Rake	Positive
Nose radius	0.2 mm
Wi	6.8 mm
BS	0.7 mm
LE	11.0 mm
S	3.59 mm
Lead angle	90°
Base material	EH520, fine-grained carbide, WC-10%CO

deposition was carried out with the substrate biased with a DC power source to introduce proper ion bombardment on the growing surface to assist in obtaining a desirable structure, grain size and film density. The chamber was evacuated to a pressure of approximately 4×10^{-6} mbar and back filled with nitrogen gas at approximately 10^{-3} mbar. The complete deposition procedure has been previously (Mubarak *et al*., 2008; Mubarak *et al*., 2005). Table 3 shows the summary of the deposition parameters.

This study used a Coro Mill tool holder R390-020C4-11L and an uncoated carbide cutting tool insert with a diameter of Ø20 mm and a nose radius of 0.2 mm (Fig. 4). Table 4 shows the geometry carbide tools used for milling Al-Si/10%AlNMMC. The

Fig. 5: Elemental chips on cutting conditions V = 230 m/min, F = 0.4 mm/tooth, D.O.C 0.4 mm

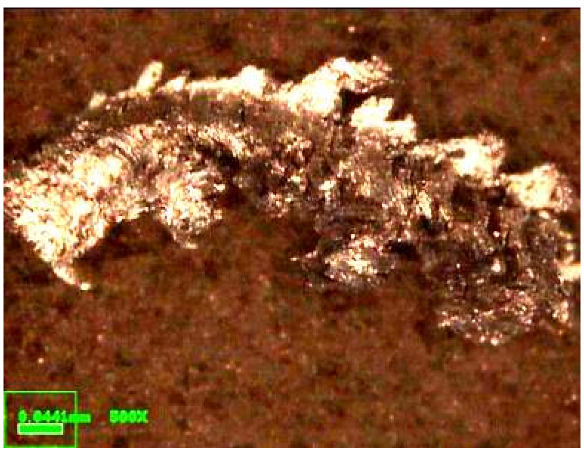

Fig. 6: Image for chip formation at cutting conditions V = 230 m/min; F = 0.6 mm/tooth; D.O.C 0.3 mm

Fig. 7: Image for chip formation at cutting conditions V = 230 m/min; F = 0.8 mm/tooth; D.O.C 0.5 mm

machining process was carried out using a CNC KONDIA B-640 milling machine at dry conditions. The parameters were as follows: a constant cutting speed of 230 m/min, feed rates of 0.4, 0.6 and 0.8 and cutting depths of 0.3, 0.4 and 0.5 mm.

RESULTS AND DISCUSSION

Chip formation and different feed rates and cutting depths: The chips were formed because of the shear between the work piece and cutting chips (Ghani and Yong, 2006). Figure 5 to 7 show the chip shapes formed during the dry milling of Al-Si/10%AlN MMC by using the TiN-coated carbide developed by SIRIM. The chips were small, short and discontinuous with outer face cracks. Ozcatalbas (2003) and Said *et al*. (2013) also observed this form when machining Al composite materials.

As shown in Fig. 7, the resulting chip was thick with cracks at a cutting speed of 230 m/min, feed rate of 0.8 mm/tooth and cutting depth of 0.5 mm. This result was due to the fact that the increase in feed rate results in the increase in tool-chip contact length, which increases the temperature of the surface of the work piece (Radhika *et al*., 2013). The band lines also affected the three types of body wears during cutting, which caused wear on the cutting tools easily and quickly.

These chips were also observed by Ozcatalbas (2003). He found that chip volume increases with the gross thickness of the segment. He added that these phenomena occurred because of the sheet-like structure and the low hardness of the material. According to Lin *et al*. (1997), low hardness and high ductility are known to cause adhesion period but reduce the slip period in segment formation. The chip formation changed at a cutting speed of 230 m/min, but different results were obtained for different feed rates and cutting depths. Figure 5 illustrates the chip formation at a feed rate of 0.4 mm/tooth and a cutting depth of 0.4 mm and Fig. 6 illustrates the formation at a feed rate of 0.6 mm/tooth and a cutting depth of 0.3 mm. The chip formations in Fig. 5 and 6 seemed shorter compared with that in Fig. 7, which shows formation at a feed rate of 0.8 mm/tooth and a cutting depth of 0.5 mm. According Ghani and Yong (2006) microstructure changes in the chip are also affected by the addition of cutting speed, constant chip thickness, or cutting depth and other factors such as hardness of the work piece (Said *et al*., 2013).

CONCLUSION

The chips formed during the machining process of Al-Si/10%AlN MMC by using TiN cutting tool insert developed by SIRIM were small, short and discontinuous with outer face cracks. The main mechanism of chip formation involved the initiation of cracking of the outer surfaces, which were chip-free because of the high shear stress. The chip lengths had different sizes, which were based on feed rate and cutting depth.

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