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Effect of chilled air on tool wear and workpiece quality during milling of carbon fibre-reinforced plastic

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ABSTRACT

Carbon fibre reinforced plastic (CFRP) is a composite which has the best strength to weight ratio among the construction materials. It becomes valuable as the demand for this composite has increased dramatically especially in automobile and aerospace industry. The need in these industries such as light weight, but retain high strength, make CFRP better choice than steel. CFRP is also known as an expensive material, since an expensive chemical treatment is required in the fabrication process. Therefore, the manufacturing cost of CFRPs' parts need to be minimized, the factors that influenced the end product's surface quality such as cost of severe tool wear, which shortens the tool life, fibre pull-out and delamination of CFRP need to be eliminated. Many studies on tool geometries, cutting tool materials, and cutting parameters have been done to overcome these problems. In this study, chilled air of $-10\,^{\circ}$C was applied to the cutting tool using a vortex tube, which is new in the machining of fibres, to minimize the heat generated during machining. Cutting speed of 160–200 m/min and a feed rate of 0.025–0.05 mm/rev on solid uncoated carbide during the milling process were discussed. At room temperature conditions, it is observed that the wear area is found polished and shining. Under room temperature cutting condition, the wear region is high at higher cutting speeds and feed rates, but in chilled air machining, these types of wear of the carbide tool are found less at higher cutting speeds and feed rates. The improvement in tool life while applying chilled air during machining of CFRP is 1.6% and 12.1% at lowest feed rate and cutting speed; while 31.8% and 45.6% longer tool life of carbide cutting tool is observed at highest feed rate and cutting speed under chilled air machining compared to room temperature machining. The delamination factor of CFRP is also found to improve at higher cutting speeds during chilled-air machining.

1. Introduction

Carbon fibre reinforced plastic (CFRP), glass fibre reinforced plastic, (GFRP) and aramid fibre reinforced plastic (AFRP) are fibre reinforced plastic (FRP) composites which are widely used for both low and high technologies engineering applications [1] which involving design, equipments and finished products. Among these fibres, carbon fibre (CF) not only offers the maximum degree of strength and wear resistance enhancement but also boosts the thermal conductivity, which is crucial from a tribological point of view [2]. CFRP has been an alternative to stainless steel and other materials, especially in corrosive industrial application [3], as it has a high modulus, high specific strength, high damping, low thermal expansion, and good dimensional stability [4,5]. CFRP is also stronger than steel and stiffer than titanium while retaining its lighter weight. Therefore, carbon fibre is commonly used for structural components of aircrafts, resulting in improved fuel economy [6].

Because CFRP composites contain two material phases with drastically different mechanical and thermal properties, there are complicated interactions between the matrix and the reinforcement during machining [7]. Users of CFRP experience such disadvantages as high abrasive wear on the tool, low quality of surface roughness, fibre pull-out, and etc during machining. Therefore, the knowledge and experiences used in conventional materials cannot be applied to this new material [8]. Thus, to overcome the problems that arise during machining CFRP, many studies have been done to improve the machinability.

The abrasive nature of FRP causes the severe wear on the cutting tool during machining. It has been reported that the FRP machining mechanism is due to the combination of plastic deformation, shearing and bending rupture. These mechanisms depend on the flexibility, orientation and toughness of the

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Nomenclature

CFRP	Carbon Fibre Reinforced Plastic
GFRP	Glass Fibre Reinforced Plastic
AFRP	Aramid Fibre Reinforced Plastic
RT	Room temperature
AC	Chilled air
VB	Flank wear
VC	Notch wear
Tl	Tool life
Fd	Delamination factor
$W_{\max}$	Maximum width of damage
W	Width of cut

fibres [9]. Active wear is found mostly on the flank and nose area of the cutting tool [10]. The nose wear on the cutting tool may be subjected to the dynamic loading [11] and it has been reported that the wear on the flank area is associated with adhesion and intense abrasion. Typically crater wear does not occur on the cutting tool when machining FRP [12].

Cutting parameters affect wear when machining CFRP. In 1999, Ferreira et al. reported that the influence of the cutting velocity more significantly affects tool wear when it reaches the critical peak [13]. The increase in feed rate during machining, which produces incomplete machining at a faster traverse, leads to higher tool flank wear. Although the depth of cut only plays a minor role in the composite machining process [14], abnormal increases in the depth of cut increase the heat generation and wear on the tool [12]. Rahman et al. [15], found that as a cutting tool, tungsten carbide, WC is better than cubic boron nitrate, CBN and ceramics at low cutting speeds, whereas CBN is the most suitable insert for FRP composite at a higher cutting speeds. However, in 2002, Teti concluded that due to its low wear resistance, CBN, which is as expensive as polycrystalline diamond, PCD, presents no advantage [16].

In 1993, Hocheng et al. reported that when the fibres are at 45°, cutting becomes more difficult because the tool is more liable to slip in addition to shear, which involves tension, thus leaving many uncut fibres as burrs [17] and subsequently influence the performance of the tool and quality of the surface. Kim [7] conducted a study on delamination and concluded that the delamination type of cutting occurred at positive rake angles when the fibre angle was 90°. To avoid delamination damage, Caprino et al. suggested that the feed rates used in machining must be much lower than those used for metal [18]. In addition to the cutting parameters and fibre orientation, the drill diameter also affects delamination on the FRP surface. The delamination size increased with larger drill diameter due to the increase in thrust force as a result of the increased cross-sectional area of the undeformed chip [19].

Other than tool wear and delamination, which are strongly dependent on the cutting parameters, tool geometry, and cutting force [20], a high cutting speed and an increase in feed rate can also result in a high surface finish [8]. Many approaches have been tried to improve the machinability of CFRP such as using of various type of cutting tools, varying the carbon fiber orientation, using different machining setups etc. It is known that the heat generated during machining CFRP is one of the factors that influenced the quality of the end product and reduce the cutting tool life. Cooling techniques such as cryogenic cooling, minimum quantity lubrication (MQL), flood cooling, etc have been applied during machining to reduce the heat generated. In this paper, the application of vortex tube in the experiment setup where chilled air at flow rate of 4.10 m/s, and a temperature of -10 °C was used to reduce the heat generated during machining CFRP. The influence of different cutting parameters under room-temperature and chilled-air machining on the performance of the uncoated carbide tool and their effect on the surface of CFRP panels were also studied and discussed. The force from the compressed air of 0.55 MPa was required to produce the chilled air whereas the dry cutting or room temperature machining had no air force during machining.

2. Experiments

2.1. Research methodology

The experiments were performed on a laminate panel of CFRP with dimensions of 205 × 300 × 3 mm. An illustration of the panel is shown in Fig. 1. The CFRP panel, which was made using the hand lay-up method, contained eight layers of carbon fibres with 1 layer of tedlar film and layer of syskin. Additionally, the orientation of the panel was 0/45° and was subjected to an autoclave process before machining. The panel was fabricated by CTRM Aero Composite Sdn. Bhd, Malaysia, a company known for fabricating fibre reinforced plastic (FRP) panel and assembling airplanes in Malaysia.

Two flute solid uncoated carbide end mills (S2FE-080) with diameters of 8 mm, a helix angle geometry of 30°, and length of 60 mm which was supplied by Kaizan Solution, Malaysia were

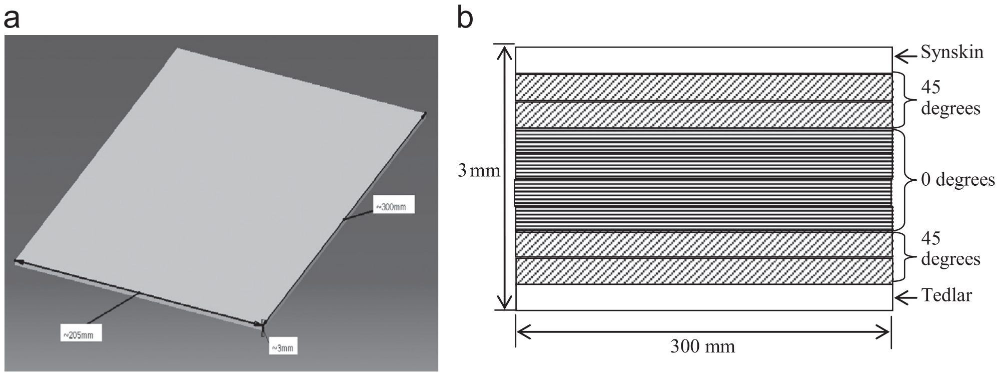

Fig. 1. Illustration of the panel (a) The dimension of the panel and (b) Layers of a panel.