Journal of Manufacturing Processes 31 (2018) 286–300

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Development of single step drilling technology for multilayer metallic-composite stacks using uncoated and PVD coated carbide tools

C.L. Kuo [a,1], S.L. Soo [a,*], D.K. Aspinwall [a], C. Carr [b], S. Bradley [b], R. M'Saoubi [c], W. Leahy [d]

[a] Machining Research Group, Department of Mechanical Engineering, School of Engineering, University of Birmingham, Edgbaston, Birmingham, UK
[b] GKN Aerospace Services Ltd., Composites Research Centre, Isle of Wight, UK
[c] Seco Tools (UK) Ltd, Springfield Business Park, Alcester, UK
[d] Element Six Ltd., Harwell, Didcot, UK

ARTICLE INFO

Article history:
Received 18 August 2017
Received in revised form
19 November 2017
Accepted 26 November 2017

Keywords:
Drilling
Hole quality
Surface integrity

ABSTRACT

The paper details experimental trials to evaluate the performance of uncoated and PVD coated tungsten carbide twist drills, for single shot drilling of 3-layer metallic-composite stack workpieces. A full factorial experiment was undertaken involving variations in feed rate (0.05 and 0.08 mm/rev) and drilling strategy (with and without pecking cycle), in addition to the tool coating (TiAlN/TiN). All of the uncoated drills machined 180 holes without exceeding the flank wear criterion of 0.3 mm, regardless of feed rate level or drilling strategy. In contrast, tool life for the coated drills was ~20-50% lower (90–148 holes). Thrust force decreased by ~12% when operating at the higher feed rate while use of coated drills led to an increase of up to 18% due to the larger cutting edge radius. Conversely, the hard/ceramic coating provided greater wear resistance at the peripheral corner of the drill resulting in lower torque (up to ~10%) compared to the uncoated tool. Furthermore, holes produced utilising the TiAlN/TiN coated drills typically exhibited superior geometrical accuracy in terms of diameter, out of roundness and cylindricity. Drilling at the lower feed rate of 0.05 mm/rev however generated larger exit burrs by up to ~90%.

1. Introduction

The composition of materials utilised in the design and construction of modern civil aeroplane structures has changed dramatically over the past 20 years. In particular, there has been a significant escalation in the use of carbon fibre reinforced plastic (CFRP) composites, which now accounts for over 50% of the weight in the Airbus A350 and Boeing B787 compared with ≤20% in aircraft manufactured prior to 2000 [1]. This is largely attributed to the superior strength to weight ratio of CFRP, which is typically ~750 kN m/kg [2] compared to metallic materials such as titanium and aluminium alloys of ~200–250 kN m/kg, enabling lighter airframes and hence enhanced fuel efficiency. However, in highly loaded sections of the fuselage and wings, the use of two or three layer metallic-composite stack arrangements are essential to provide the necessary structural integrity in service without imposing a significant penalty on overall weight. The linking of these hybrid assemblies is primarily achieved via mechanical joining techniques, with interference fit fasteners having replaced conventional rivets in many areas, providing a reduction in the number of joints required and increased tensile load capability of the structure [3]. Unfortunately, such fasteners require the production of more accurate holes with tighter tolerances, which are generally only attainable using multi-step operations including pre-drilling of individual layers followed by de-burring prior to assembly of the stacks and final reaming [4].

The development of single-shot drilling technology for multilayer CFRP-metallic stacks has been the focus of considerable research in recent years not only as a solution to improve productivity, but also to reduce/avoid the misalignment of holes during assembly of the sandwich configuration [5]. A large majority of published research on this topic has involved twin layer arrangements comprising CFRP/Al or CFRP/Ti alloys. Use of high hardness/wear resistant tooling employing chemical vapour deposited (CVD) diamond coatings or polycrystalline diamond (PCD) blanks on tungsten carbide (WC) tools are generally recommended for drilling CFRP, due to the extremely abrasive and inhomogeneous nature of

* Corresponding author at: Machining Research Group, Department of Mechanical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK.
E-mail address: s.l.soo@bham.ac.uk (S.L. Soo).
1 Present address: Department of Mechanical Engineering, National Taiwan University of Science and Technology, #43, Sec. 4, Keelung Road, Taipei 106, Taiwan, ROC.

https://doi.org/10.1016/j.jmapro.2017.11.026
1526-6125/

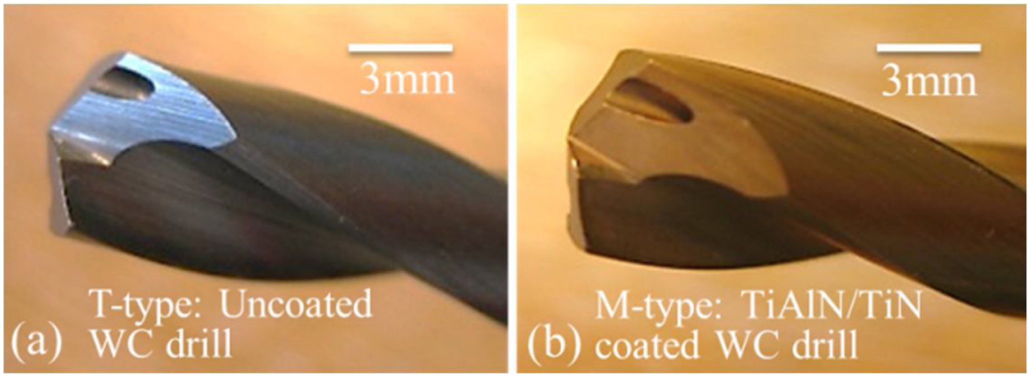

Fig. 1. Micrographs of (a) uncoated (T-type) and (b) TiAlN/TiN coated (M-type) WC twist drills.

Table 1
Variable parameters and levels.

Factor	Level 1	Level 2
Tool material	Uncoated WC	TiAlN/TiN coated WC
Feed rate	0.05 mm/rev	0.08 mm/rev
Drilling strategy	Without pecking	With pecking

Table 2
Full factorial test array.

Test No.	Tool material	Feed rate	Drilling strategy
1	Uncoated WC	0.05 mm/rev	Without pecking
2	TiAlN/TiN coated WC	0.05 mm/rev	Without pecking
3	Uncoated WC	0.08 mm/rev	Without pecking
4	TiAlN/TiN coated WC	0.08 mm/rev	Without pecking
5	Uncoated WC	0.05 mm/rev	With pecking
6	TiAlN/TiN coated WC	0.05 mm/rev	With pecking
7	Uncoated WC	0.08 mm/rev	With pecking
8	TiAlN/TiN coated WC	0.08 mm/rev	With pecking

the workpiece material [6]. However, despite relatively low wear rates, the CVD-diamond coating can be prone to peeling/chipping and delamination, particularly when cutting at high feed rates, due to insufficient adhesion strength between the thin film and substrate or inadequate preparation of the tool surface prior to coating [7]. In contrast, PCD tooling is the preferred option for the machining of high volume aluminium-silicon alloy components typically employed in the automotive industry as well as other non-ferrous/non-metallic materials including composites [8].

Montoya et al. [9] investigated the performance of different coatings (diamond, TiAlCrN, AlTiSiN-G) against uncoated WC tools when drilling 6 mm diameter holes in 21 mm thick CFRP/AA7010 stacks, at a cutting speed and feed of 55 m/min and 0.04 mm/rev respectively. The diamond coated drill exhibited the lowest wear rate with a flank wear of ~120 μm compared to almost 250 μm for the uncoated tool after 250 holes, with peeling of the diamond coating only commencing after 150 holes. This was despite average thrust forces generated by the former being ~30–100% higher than the other tools due to the larger cutting edge radius of the diamond coating (15 μm as opposed to 9 μm for the uncoated tool). Both the TiAlCrN and AlTiSiN-G coatings began to delaminate after only 5 holes, with complete removal from the tool substrate observed after machining 75 holes. The superior wear resistance of the diamond coating led to consistent hole diameter and surface roughness (below 1.6 μm Ra in Al and 3.2 μm Ra in CFRP layers) over the test duration. A twin cutting edge design (similar to a Brad point drill) was evaluated against a conventional twist drill when machining 5 mm diameter holes in thin CFRP/AA7075 stacks (overall thickness of 6.17 mm) by Zhang et al. [10]. All of the drills were CVD-diamond coated with a full factorial experiment performed involving varying cutting speed (42.5–92.5 m/min) and feed (0.03–0.07 mm/rev), each at 5 levels. Results indicated that tool geometry played a more significant role than operating parameters, with the twin cutting edge drill providing greater hole accuracy (average diameter deviation of 5 μm from nominal value), reduced thrust forces (~20% lower) and better surface roughness in the CFRP layer (1–2 μm Ra as opposed to 2–4 μm Ra). Associated tool life trials undertaken at a cutting speed and feed rate of 63 m/min and 0.04 mm/rev respectively, showed a gradual progression of drill flank wear (~0.08 mm) and thrust force up to ~400 holes, following which both factors increased dramatically with peeling of the diamond coating being the main wear mode. An innovative drill design for improving the one-shot drilling of CFRP/Al stacks was developed by Segawa et al. [11], incorporating a smaller diameter multi-angle point edge and a larger chamfered finishing section (similar to a step drill) together with a high helix angle. The arrangement of the pilot section functioned to reduce thrust force by deflecting a larger proportion of the cutting forces in the radial direction thereby minimising delamination while also enhancing breakage of the Al swarf and aiding evacuation. Hole sizing was then achieved by the trailing finishing section, which also removed any initial exit burrs. Experimental benchmarking trials involving CFRP/Al stacks showed that the new drill design (CVD-diamond coated WC) decreased peak thrust forces by ~70% in the Al layer (~650 to ~200 N) compared to a traditional twist drill, while diameter variation in the CFRP section after machining 500 holes did not exceed ~25 μm.

Zitoune et al. [12] studied the effects of tool diameter (4, 6, 8 mm), rotational speed (1050, 2020, 2750 rpm) and feed rate (0.05, 0.10, 0.15 mm/rev) when drilling CFRP/AA2024 stacks (4.2/3.0 mm thick) with uncoated WC drills. Variation in tool diameter and feed rate had a more prominent influence on thrust force, torque and chip breaking than cutting speed, while only feed rate was seen to affect hole surface roughness in the CFRP layer (~2–4 μm Ra at low feed rate and ~6–8 μm Ra at high feed rate). Additionally, thrust forces were stable with no apparent signs of workpiece delamination or damage up to ~60 holes, however hole quality deteriorated beyond this point, with uncut fibres and edge chipping prevalent. Subsequently, trials were carried out to investigate the performance of 6 mm diameter, nano-composite coated (nanocrystalline-CrAlN/amorphous-Si_3N_4) WC tools at similar operating parameters (1050–2750 rpm and 0.05–0.15 mm/rev) when drilling CFRP/AA2024 stacks [13]. Thrust forces in the Al and CFRP sections were up to ~47% and 20–25% lower respectively, while average hole surface roughness in the CFRP layer decreased by ~40% when machining with the coated as opposed to uncoated drill. A recent industrial based assessment involving one-shot drilling of CFRP/Al stacks in a robotic manufacturing cell using veined PCD drills (4.1 and 7.9 mm diameter) was reported by Sahin et al. [14]. Variation in diameter after drilling 30 holes was within