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Burr formation and hole quality when drilling titanium and aluminium alloys

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Abstract

Following a brief review of key factors affecting burr size and hole quality, the paper details experimental work involving the drilling of Ti-6Al-4V titanium alloy together with Al7010-T7451 and Al2024-T351 aluminium alloys. Chemical vapour deposited (CVD) diamond coated carbide drills were used for the aluminium workpieces while uncoated carbide tools were employed for the titanium material. An experimental design based on response surface methodology was implemented to identify the effects of cutting speed and feed rate (each at 3 levels) on burr size, hole diameter and out of roundness as well as tool flank wear. Exit burr size was smallest when operating at the intermediate feed rate level for all three workpiece materials, with reductions in burr height of up to 50% and 75% for the titanium and aluminium alloys respectively. Out of roundness did not exceed 0.03 mm while the deviation on hole diameter was less than 0.04 mm in all trials, even after drilling 60 holes.

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Keywords: Drilling; Burr formation; Aerospace alloys

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1. Introduction

Burr formation and poor hole geometrical quality can be detrimental to fatigue life as well as hinder the assembly and functionality of drilled components. This generally necessitates the application of costly additional operations such as reaming and deburring. The generation of burrs is typically influenced by various parameters including tool geometry and material, workpiece material properties, part geometry and process conditions [1]. Feed rate and cutting speed however are the easiest factors to control for burr minimisation, the rest of the aforementioned parameters being largely application dependent.

Numerous researchers have investigated the effects of varying cutting speed and feed rate with respect to the reduction of burr size in drilling. Sofronas and Taraman [2] and Ko et al. [3] identified feed rate as being the most significant parameter affecting burr size with a proportional relationship when drilling different steels (AISI 1018 and SM45C alloy). Conversely, Pande and Relekar [4], Stein and Dornfeld [5] as well as Karnik and Gaitonde [6], reported a non-linear trend between burr size and feed rate when drilling similar workpiece materials. Dornfeld et al. [7] however showed that both feed rate and cutting speed had limited influence on burr size when drilling Ti-6Al-4V, although this could be attributed to the restricted range of cutting speed (6-10 m/min) and feed rate (0.04-0.20 mm/rev) levels employed in the experiments. Subsequent work by Kim et al. [8] involving two types of stainless/alloy steels (AISI 304L and 4118), led to the development of an experimentally based burr control chart which suggested that feed rate and the interaction between feed rate and cutting speed had a significant impact on burr formation.

Drilled hole geometrical quality is primarily quantified by the out of roundness/cylindricity and diameter accuracy parameters. Early investigations of hole quality revealed

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that use of low feed rate reduces out of roundness and enhances alignment of the hole [9] while hole diameter deviation was reported to increase with feed rate and cutting speed [10]. In contrast, Abele et al. [11] showed that cutting speed had the greatest effect on hole roundness while the contribution of feed rate was marginal. In addition to the relatively narrow range of feed rates assessed (on average ranging from 0.07- 0.16 mm/rev), the majority of published work precludes the use of statistical analysis techniques to correlate the influence of drilling conditions on resulting burr size and hole quality. This in part explains the contradictory conclusions reported in the literature.

The present paper details results from statistically designed experiments investigating the effect of cutting speed and feed rate on burr size, hole quality and tool wear following through hole drilling of aerospace grade titanium and aluminium based alloys.

2. Experimental work

2.1. Workpiece material, tooling and test procedures

Three different workpiece materials were evaluated including an annealed Ti-6Al-4V titanium alloy having a tensile/ultimate yield strength of 825/895 MPa, together with 2 different solution treated and aged aluminium alloys; 7010/7050-T7651 and 2024-T351, having tensile/ultimate yield strengths of 450/520 and 290/430 MPa respectively. Dimensions of the strip workpiece specimens for hole quality and surface integrity assessment were 17 x 120 x 6 mm (width x length x height), while square workpiece plates 120 x 120 x 6 mm were used for tool wear trials. The tool life/end of test criterion was a flank wear of 0.1 mm or a maximum of 60 drilled holes.

The cutting tools used were twin fluted, 6.35 mm diameter solid WC twist drills supplied by MAPAL Ltd., with geometry and coating details listed in Table 1. Tool overhang was 57 mm in all trials with run-out < 10 µm.

Table 1. Drill geometry and coating details.

Factor	Workpiece material	
	Ti-6Al-4V	AA7010/AA2024
Product code	MEGA-Stack-Drill-AF-C/T	MEGA-Stack-Drill-AF-A/C
Drill point angle	135˚	120˚
Drill helix angle	34˚	34˚
Point geometry	Split point with gashed/thinned chisel	Split point with gashed/thinned chisel
No. of margins	3	2
Tool coating	Uncoated	CVD diamond

All tests were carried out on a Matsuura FX5 high speed machining centre with a maximum spindle speed of 20,000 rpm rated at 15 kW and variable feed rate control of up to 15 m/min. The strip specimens were held in a bespoke fixture mounted on a Kistler drilling dynamometer (model 9273) connected to Kistler 5011A charge amplifiers, with data recorded and processed on a computer using DynoWare software. The plate workpieces were clamped onto a drilling jig with an array (10 x 10) of pre-fabricated 9 mm diameter clearance holes. Trials were undertaken wet using Hocut 3380 water based emulsion delivered externally (flood) at a flow rate of 52 l/min.

Assessment of hole out of roundness and diameter was carried out on a Talyrond 300 by sampling 2000 data points around the hole circumference at two pitch planes (entry, exit) for the first hole and subsequently every ten holes. Hole diameter was calculated based on the least-square circle fit of the recorded data points. Exit burr height was measured using an Alicona InfiniteFocus G5 optical microscope at 8 equally-spaced positions around the hole periphery with an average calculated over the first 5 holes drilled as described by Kim et al. [8] and Min et al. [12], in order to minimise the influence of tool wear on the results. Drill flank wear measurement was performed using a Wild M3Z tool-maker's microscope equipped with a movable stage having digital micrometers (1 µm resolution) and digital camera for image capture.

2.2. Test parameters and experimental array

Tables 2 and 3 detail the variable factors together with levels of feed rate and cutting speed selected based on recommendations from the tool supplier. Response surface methodology with a face centred central composite design was employed where the minimum recommended central runs required to achieve stable variance of the predicted responses was two [13]. Therefore, a total of ten tests were performed for each workpiece material according to the test array listed in Table 4. Statistical analysis of the results was performed using Minitab software.

Table 2. Variable parameters for drilling AA7010/AA2024 alloys.

Factor	Level -1	Level 0	Level 1
Cutting speed (m/min)	50	100	150
Feed rate (mm/rev)	0.08	0.16	0.24

Table 3. Variable parameters for drilling Ti-6Al-4V alloy.

Factor	Level -1	Level 0	Level 1
Cutting speed (m/min)	10	20	30
Feed rate (mm/rev)	0.07	0.14	0.21

Table 4. Experimental array for each material.

Test no.	Cutting speed level	Feed rate level
1	1	-1
2	0	0
3	1	1
4	-1	-1
5	-1	1
6	1	0
7	-1	0
8	0	1
9	0	-1
10	0	0