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Deep hole drilling methodology for high yield strength Inconel 718 >1000 MPa

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Abstract

Drilling of deep holes on heat-resistant superalloys like Inconel 718 can be found in specialized engineering applications involving extreme temperatures. Such exotic materials, especially at high yield strengths pose indomitable challenges in drilling deep holes. Poorly designed drills for pilot hole drilling and deep hole drilling can lead to catastrophic failures at different stages. Inappropriate selection of drilling parameters and/or drilling sequence will either drives the drills to degrade and break rapidly on one hand or adversely affect the overall productivity on another. Eventually, these incapability will result in irreparable hole straightness and costly material scraps. In this paper, a comprehensive drilling solution on general machining centers for deep holes with depth-to-diameter ratios ranging 10 to 100 is proposed. To study compatibility of drills for pilot hole drilling and deep hole drilling, three twist drill designs with distinct geometries such as point angle and chisel edge were used. Other than initial tool-work engagement efficacy, effects of bottom hole geometries on process stability using four types of single-lip deep hole drills are investigated. An intermediary reaming is performed to achieve tight IT7 tolerance. As a result, a novel parameter - 'drilling engagement ratio' is derived as a quantitative tool design guideline for deep hole drilling. Following that, practical implementation of single-lip drills are studied in detail, in conjunction with controlled edge geometries. It is found that low drilling feeds deteriorate drilling stability and lead to high wear rate as a contrary to common industry practice. Chips generated at low feed rates are more prone to break, but irregular in shape. Such irregularity improves with increasing feed rates, alongside tool wear but fails to break at high feed above 0.04 mm/ rev – resulted in ultimate tool failure. Based on extensive experimental observations, an optimal set of drilling parameters and drill designs is recommended.

Deep hole drilling, Inconel718, wear

1. Introduction

Gundrilling is a deep hole drilling process to produce miniature and high aspect ratio holes. A dedicated machine with provision of drill supports is needed to drill beyond 1 meter while shorter holes can be drilled on general machining centres with through-spindle coolant supply. Cutting is carried out with single-lip gun drills with asymmetric point geometries, unlike conventional twist drills. Such unique designs allow the balancing of active cutting forces and radial forces by the bearing surfaces in order to facilitate self-piloting action of gun drills [1]. But the use of conventional approaches in drilling deep holes on Ni-based alloys like Inconel 718 is unable to meet industry needs. With inappropriate pilot hole geometries and drilling parameters, gun drills fail catastrophically due to heat and work hardening. Due to this, the process is carried out at unneccessasry conservative parameters that leads to extremely low productivity [2]. In this paper, an optimal methodology to perform gundrilling on general machining centers for high yield strength Inconel 718 > 1000MPa is presented.

2. Pilot Hole and Gun Drill Compatibility

Drilling of deep holes on machining centers begins with the drilling of pilot holes to guide gun drills in subsequent high aspect ratio drilling. The quality of a pilot hole is governed by its diametric run-out and bottom geometry. Upon preliminary tool-work contact, gun drills engages with the bottom of pilot holes in which the cutting edges are partially loaded - leading to severe chattering. If such transient instability is not controlled, chipping on the cutting edges will be resulted.

To promote effective tool-work engagement, a new parameter known as the Drilling Engagement Ratio *DER* is introduced [3] to evaluate quantitative compatibility between bottom geometry of pilot holes and the nose grind geometry of different gun drill designs. The engagement is divided into two stages: Stage-1 involves full engagement of one of the two cutting edges while Stage-2 involves full engagement of both cutting edges. *DER* is defined as the ratio between the duration of Stage-1 over the total duration of the two stages ($ER=t_1/t_1+t_2$). Four unique contact conditions based on various geometric combinations of pilot hole and gun drill are derived and depicted in Figure 1.

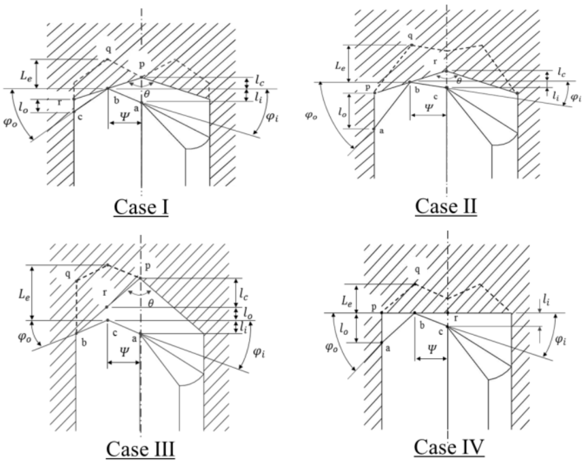

Figure 1. Geometric compatibility of pilot holes and gun drills [3].

High *DER* represents smooth tool-work engagement and vice versa. Once the optimum combination of pilot hole and gun drill designs is determined, deep hole drilling is then performed and evaluated based on the resultant thrust force, chip morphology and tool wear.

3. Experimental Study

All drilling experiments were performed on the DMU 80P duoBLOCK. The twist drills (Ø7.8mm) for pilot hole drilling and gun drills (Ø8mm) for deep hole drilling are shown in Figure 2. The speed and feed rate for pilot hole drilling were fixed at 20m/min and 0.08mm/rev respectively. For deep hole drilling, three feed rates *f* - 0.01, 0.02 and 0.03mm/rev were tested. Fuchs Ecocool emulsion 12% was constantly applied at 4MPa. Yield point of the Inconel 718 workpiece was 1028MPa.

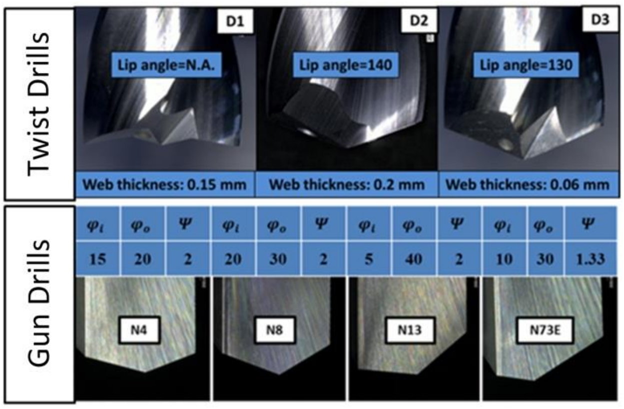

Figure 2. Determination of optimum twist drill-gun drill combination.

3. Results and discussion

3.1 Pilot hole drilling

Pilot holes with 12mm in depth were drilled with 3 different twist drill geometries. Drill D2 outperformed D1 and D3 in terms of tool life and did not experience any chipping after drilling 20 holes. D1 and D3 were unable to drill five holes before failing at web region due to the narrow webs. But none of the pilot holes could satisfy the IT7 criterion [4]. Diametric run-out was found to be in the range of 0.03-0.05mm. Hence, Ø8mm reamer was used for reaming (runout<0.01mm). For effective tool-work engagement, *ER* should be kept in the range of 0.6-1. N4, N8 and N73E are best suited with flat bottom geometries; whereas a conical bottom geometry is more suitable for N13. Flat bottom geometries were achieved through end milling after the reaming process.

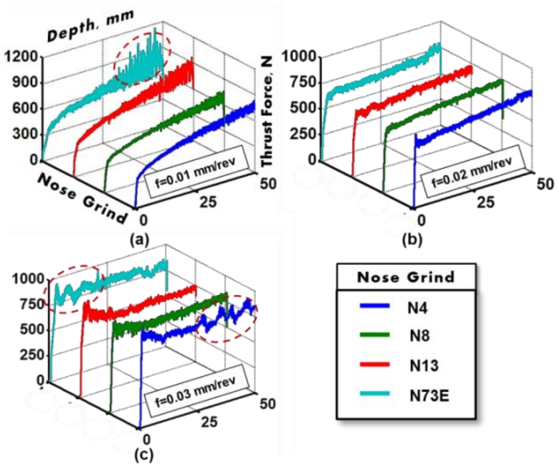

Figure 2. Thrust force at different feed rates (a) f=0.01 mm/rev, (b) f=0.02 mm/rev, (c) f=0.03 mm/rev.

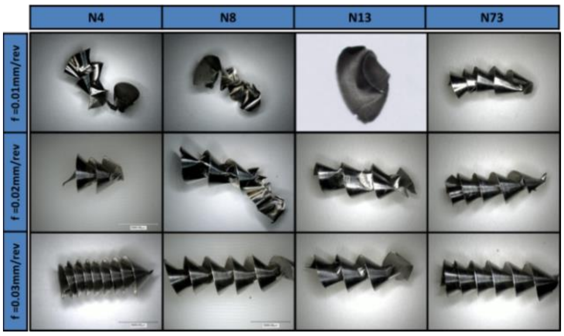

Figure 3. Chip morphology in gundrilling of Inconel 718.

3.2 Deep hole drilling

With the drilling of 50mm in depth for each cycle, flank wear *VB* improves with increasing feed rate. VB_{max} was located on the outer cutting edge where cutting speed is highest. As flank wear is developed, stability of the drilling process deteriorates. Such instability for N73E nose grind can be depicted through the thrust force distribution in Figure 2(a). At low feed rate, the chips produced were more irregular in shape except for N73E that has a large outer cutting edge angle to control the chip shape. The pitch size of the chip's helical shape increases with large outer cutting edge angle as depicted in Figure 3. Chips with smaller pitch are difficult to break and are prone to clogging. Refer to Figure 2(c), fluctuation in thrust forces are caused by the chip clogging. Chips would only break when the frictional torque on the chip exceeds the breaking torque. By increasing the feed rate, chips became more rigid and compact. At a feed rate beyond f=0.03mm/rev, the chips were completely clogged and jammed inside the hole and resulted in catastrophic drill failures. Best performance took place at f=0.02mm/rev for all gun drill designs, as shown in Figure 2(b).

4. Conclusions

Based on experimental validations, the following conclusions are reached and summarized in Figure 4:

i) Pilot holes should be reamed to ensure IT7 Tolerance.
ii) *DER* should be kept within 0.6 to 1 for effective tool-work engagement.
iii) N4, N8 and N13 gun drills require the use of pilot holes with flat bottoms.
iv) N8 gun drill yields the best deep hole drilling performance at f=0.02mm/rev.

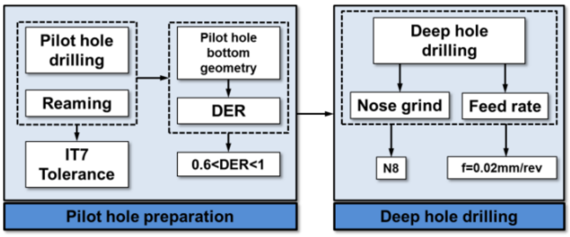

Figure 4. Optimum drilling methodology and parameters.

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