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Modification of flute geometry for enhanced tool life in gun drilling of Inconel 718

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Abstract

Deep holes with a small diameter and a high aspect ratio are usually manufactured by a gun drilling process, especially for subsea oil and gas industry. In order to protect the devices against harsh environment (i.e. highly corrosive, pressure and temperature conditions), the equipment employs high yield strength and corrosion resistance alloys such as Inconel 718. Unfortunately, it is a challenging task to drill Inconel 718 due to its difficult-to-machine characteristics. Owning to the extremely high temperature at the cutting zone, the gun drilling tool often suffers premature failure and rapid degradation. When conventional geometrical design of cutting flute is utilized, computational fluidic dynamics (CFD) simulation has shown that the supplied coolant cannot effectively reach the cutting zone and lower its temperature during gun drilling of Inconel 718. Hence, a modified geometrical design of flute is necessary to enhance the cooling flow and pressure of the supplied coolant, so as to increase the tool life. A series of CFD simulation has shown that a reduced land width of the primary clearance face below the outer cutting edge is able to enhance the cooling flow and pressure. Then, an in-house developed gun drill grinding machine equipped with an in-situ tool geometry measurement system is utilized to produce gun drills with varying land width. Gun drilling experiments on Inconel 718 using these gun drills have proven that the tool life can be increased by around 20% when an optimized land width of primary clearance face is implemented.

Deep hole drilling; Wear; Cooling; Inconel 718

1. Introduction

It has been a challenging task to perform a deep hole drilling of Inconel 718, especially gun drilling of a small diameter hole with a high aspect ratio. Inconel 718 is recognised as a difficult-to-machine material due to its rapid work hardening and poor thermal conductivity characteristics [1]. The gun drills are often suffered premature failure and rapid degradation, due to the extremely high temperature at the cutting zone, and required frequent re-sharpening [2]. This paper presents an optimization study of coolant flow by considering the effect of tool geometry (land width of primary clearance). This study helps to optimize the land width of gun drill for not only evacuating the heat efficiently, but also enhancing the tool life.

2. Experimental Methodologies

2.1. Workpiece Material

Inconel 718 has been employed as a workpiece for all gun drilling experiments. Tab. 1 describes the mechanical properties of Inconel 718 after it has been undergone an aging treatment as per ASTM B637 [3] to improve its yield strength and hardness.

Table 1. Mechanical Properties of Aged-hardened Inconel 718

Yield Strength 0.2% offset (MPa)	1103
Tensile Strength (MPa)	1327
Hardness (HRc)	45

2.2. Gun Drill Material and Tool Geometries

Ø8 x 300 mm length gun drills with single pad and dual-coolant hole configuration were employed to study the effect of land width on the tool wear. Fig. 1 illustrates a land width of primary clearance in the gun drill. The grinding of the land widths was performed by using an in-house developed gun drill re-grinding machine equipped with a telecentric camera as in-situ measurement system [4], as illustrated in Fig. 2. In this study, the selected range of primary land width is [0.075, 0.15, 0.3, 0.6, 1.2] mm, whereby the range of commercial gun drill is 0.3 ~ 0.6 mm. The primary land widths were ground and measured by the developed in-situ measurement system. This system can control the reground geometries within +/- 0.010 mm.

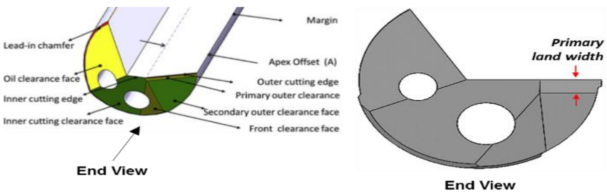

Figure 1. Tool geometry of a gun drill; (End view) land width of primary clearance

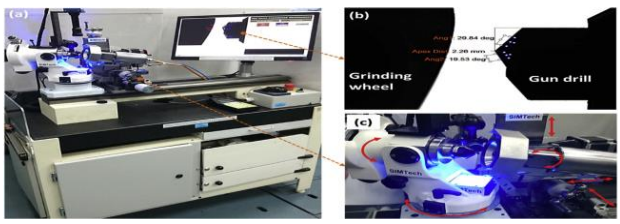

Figure 2. (a) Photographic view of developed gun drill grinding machine with in-situ measurement system; (b) Live captured image for automated measurement of gun drill geometry from telecentric camera; (c) Enlarged view of a setup for gun drill re-sharpening.

2.3. Computational Fluidic Dynamics Simulations

Computational fluidic dynamics CFD model developed in our previous studies [5,6] was employed to study the effect of the primary land width on the coolant flow behaviour. Fig. 3 explains the boundary conditions and the coolant flow behaviour in the CFD simulation. The CFD simulations were conducted using ANSYS CFX 14.0, which is based on the control volume method. The domain was meshed with a swept method and the face sizing with 0.01~0.1 mm element sizes were tested. Due to no significant change in the numerical result, a minimum cell size-0.1mm was chosen.

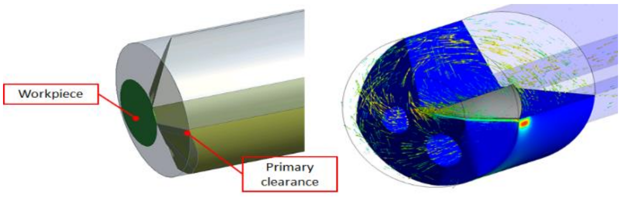

Figure 3. Boundary conditions and coolant flow behavior

2.4. Gun Drilling Experiments

Several gun drilling experiments have been performed on an Inconel 718 workpiece using 5-axis CNC milling machine (DMG MORI, DMU 80 P duoBLOCK). For every drilling experiment, a pilot hole is firstly prepared, which acts a drill bush to guide the gun drill. The hole is drilled by a twist drill and its hole bottom is flattened using an endmill. Lastly, it is finished by a reamer to a precise diameter, which is about 0.005-0.012 mm larger than the gun drill's diameter. Tab. 2 describes the experimental conditions for all gun drilling experiments which are selected based on our previous studies [4-6]. During the experiment, the tool wear conditions of five different primary land widths would be analysed using Keyence Digital Microscope VH-1000. The experimental results shall be presented and discussed in the next section.

Table 2. Gun drilling conditions

Spindle Speed, rpm	800
Coolant Pressure, Bar	40
Coolant	Fuchs Ecocool 701 with 12% wt oil
Feed or chip load, mm/rev	0.008
Drilling Depth, mm	50

3. Experimental Results and Discussion

Fig. 4 presents the comparison of simulated coolant flow behaviour between the different primary land widths. It can be observed that the coolant flow and pressure towards the primary clearance face below the cutting edge improve as the primary land width reduces. As a result, a better cooling performance reduces the high cutting temperature at the cutting zone when the optimized land width is being implemented.

Fig. 5 shows the comparison of flank wear between different primary land widths. The results indicated that gun drill with smallest land width of 0.075 mm having the least amount of flank wear. As compared the commercial land widths (0.3~0.6 mm), an improvement of tool life is found to be > 25% when the optimized land width of 0.075 mm is implemented. This trend matches well with the CFD predictions, whereby the CFD analysis reveals that the gun drill with smallest land width is capable to deliver the highest coolant pressure and better coolant supply to the cutting edge (flank and rake face) as others with larger land widths. Therefore, the primary land width is recommended to be 0.075 mm for having a longer tool life.

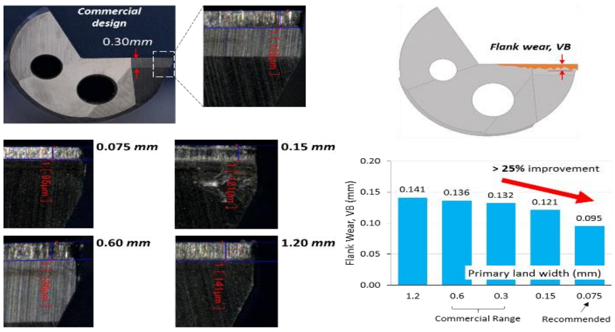

Figure 5. Resulted flank wear, VB w.r.t. different primary land widths

4. Conclusions

The proposed modification of the primary clearance's land width has been experimentally validated with the successful computational fluidic dynamics CFD simulations and gun drilling of Inconel 718. It is recommended for the gun drill having the optimized land width of 0.075 mm to enhance not only the cooling flow and pressure, but also the tool life. Thus, this tool geometry optimization serves as an attractive solution in overcoming the manufacturing challenges in the deep hole drilling of difficult-to-cut materials.

References

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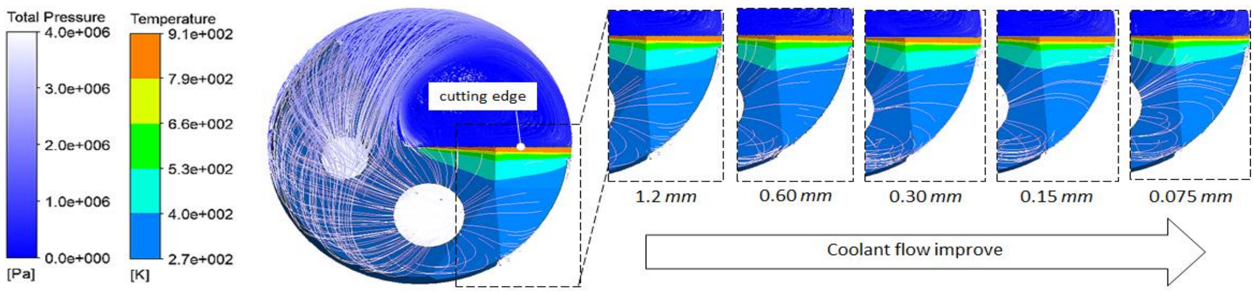

Figure 4. Simulated results of coolant flow behaviour w.r.t. different primary land widths. Improvement of coolant flow with decreasing land width is observed.