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Technical Paper

The effects of pilot hole geometry on tool-work engagement efficacy in deep hole drilling

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ABSTRACT

Deep hole drilling using single-lip drill (SLD) without a starting bush induces a severe cutting edge chipping if the pilot hole profile is not selected properly. In this paper, a new parameter 'Engagement Ratio' (ER) is introduced to determine appropriate pilot hole profile. ER depends on pilot hole and tool geometry combination. Application of ER is illustrated with geometrical model for four different engagement conditions. The range of values of ER for Inconel 718 was defined based on experimental results to ensure smooth engagement. Moreover, this approach can be extended to select the pilot hole geometry for other materials.

1. Introduction

Inconel 718 is widely used in the petroleum industry for valves, drill collars and completion equipment due to its corrosion resistivity and physical stability at high temperature [1]. Deep hole drilling is one of the common machining operations for the fabrications of these components. Deep holes with aspect ratios less than 50 can be machined using normal CNC machining centers if provided with internal coolant supply. Single-lip drill (SLD) is generally used for such components as the chip breakability and evacuation is one of the major problems faced while drilling Ni-based alloys [2,3].

The drill geometry for SLD is selected on the basis of workpiece material, favorable chip shape, hole surface integrity and accuracy requirements of the hole. However, for difficult to machine materials such as Inconel 718, the effects of SLD geometries have not been sufficiently understood. In conventional deep hole drilling using SLD (also known as gundrilling), a guide bush is used as shown in Fig. 1(a) when a special purpose deep hole machinery is available. For smaller components, installation and mounting of a guide bush are difficult, time consuming and expensive. Moreover, inner diameter tolerances of guide bushes are difficult to control. If the tolerance is excessive, drills will not be properly guided. During preliminary engagement, the drill will slip randomly over the entrance face also known as 'the walking phenomenon' which will ultimately result in 'bell-mouth formation' where the entrance hole diameter is unnecessarily widened [4]. On the other hand, if the tolerance is insufficiently provided, drills will be overly constrained and often break catastrophically upon engagement.

In the absence of specialized deep hole drilling machines, general purpose machining centers and lathe machines can be used alternatively for drilling deep holes. Here, guide bush is replaced with pilot holes to guide SLD drills into the workpiece as shown in Fig. 1(b). These pilot holes are necessary to facilitate self-piloting action of SLD [5] during preliminary tool-work engagement. Due to the unique asymmetrical geometry of SLD, the cutting forces generated on cutting edges are balanced by the reaction forces on the guiding pads of the drills to facilitate self-piloting. However, preliminary engagements of SLD drills are not stable because the cutting edge is in partial contact with the workpiece. Moreover, drilling of alloy 718 produces higher forces than conventional materials which increases the tendency of chipping formation on cutting edges during tool-work engagement if pilot hole geometry is not established properly.

Conventional drilling setup using guide bushes was previously studied by Astakov (2002) [4]. It was reported that gundrilling stability during engagement was influenced by the type of guide pads, diameter of pilot bush and geometry of SLD. Moreover, when pilot holes are made to replace the use of guide bushes, the geometry of pilot holes be it flat or conical (Fig. 1(b)) will affect

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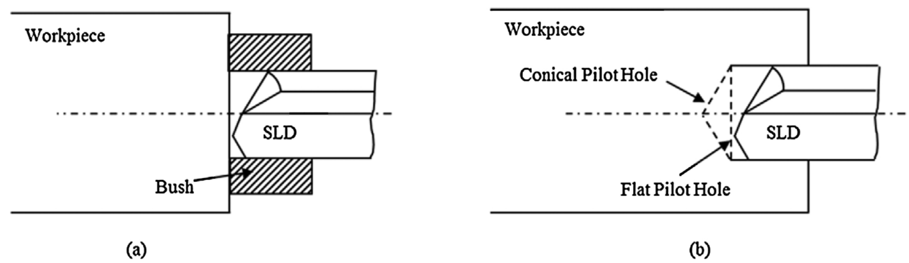

Fig. 1. (a) Conventional deep hole drilling set-up with pilot bush. (b) Deep hole drilling with flat or conical pilot hole profile.

tool-work engagement efficacy, as well. This paper aims to explain the engagement behavior of different SLD geometries with two commonly used pilot hole geometries to provide a guideline for the determination of appropriate SLD and pilot hole geometry combinations.

2. SLD engagement

2.1. Stability during engagement

The forces generated on the cutting edge during drilling can be resolved into three major components, namely radial (F_r), cutting (F_c) and thrust (F_t). The force system on the SLD drill is stable when the resultant of cutting and radial force (F_{rc}) are balanced by the reaction forces (F_{r1}, F_{r2} and F_{r3}) at guiding pads as depicted in Fig. 2(a).

During the engagement the cutting edges are partially in contact with the workpiece which leads to instability and consequently chipping of cutting edges. In general, thrust force has higher magnitude as compared to resultant of cutting and radial component. Due to the high strength of alloy 718, the cutting forces are higher in SLD and any sudden change in the thrust force leads to chipping at the cutting edge. The pilot hole profile has direct effect on thrust force and it depends on the time required for the total engagement. The engagement of the SLD with pilot hole can be divided into two phases as shown in Fig. 2(b). The cutting starts when drill touches the workpiece and at the end of Phase 1, one of the edges completes the engagement. Phase 2 ends when both the edges are completely engaged with workpiece. The time required for this engagement has significant influence on the thrust force and eventually on the tool chipping.

The rate of change of thrust force during engagement is defined by Slope I and Slope II for Phase I and Phase II, respectively. If one of the edges engages quickly with the workpiece, the sudden change in the thrust force will cause chipping on the cutting edges. However, this phenomenon is unexplored and often subjected to experience of the machine tool operator. Here, a new parameter is introduced for selection of pilot hole for the given drill geometry.

2.2. Engagement ratio

To compare performance of SLD during engagement, a new parameter called 'Engagement Ratio' (ER) was introduced. It can be defined as the time required for completion of Phase I divided by total engagement time.

$$\text{Engagement ratio} \quad (ER) = \frac{t_{ei}}{t_e}$$

where t_{ei} is the time required for completion of Phase I and t_e is the time taken to complete engagement of both the cutting edges. The ratio lies in the range of 0–1. The ER has direct influence on the Slope I of thrust force. The cutting edge will be suddenly engaged with workpiece when ER is near 0 and Slope I will be near 90°. Whereas, cutting edges will engage smoothly when ER is near 1 meaning the time taken for completion of Phase I and total engagement time are equal. For smoother engagement ER near 1 is preferred. The ER can be calculated based on the combination of tool and pilot hole geometry.

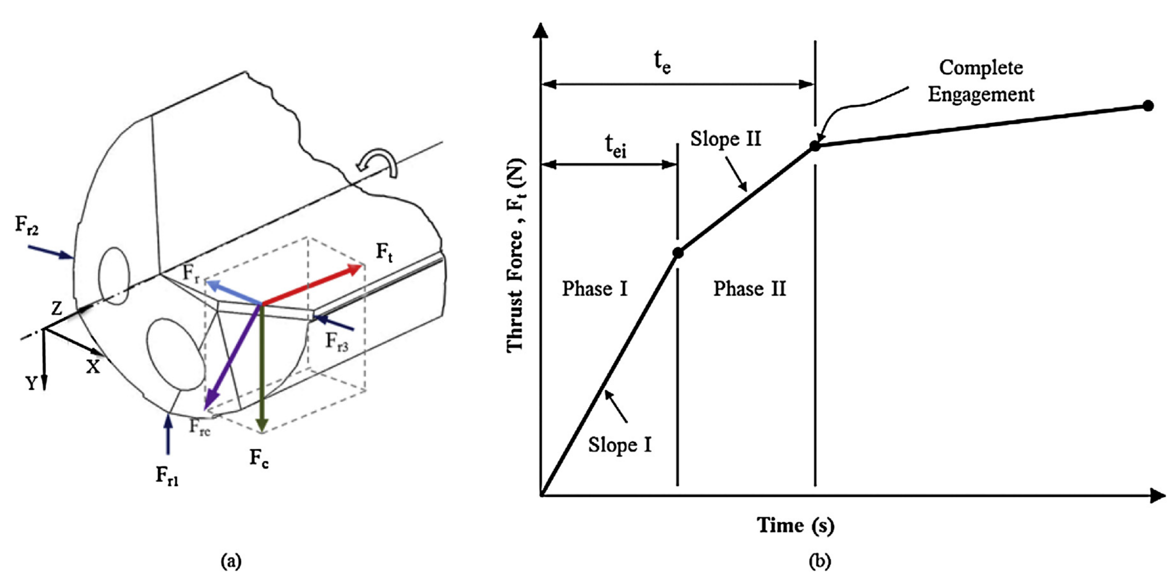

Fig. 2. (a) Force system on SLD tool. (b) Thrust force variation during engagement.