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Novel drill bit with characteristic web shape for high efficiency and accuracy

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ABSTRACT

This study proposes a novel drill design to reduce the cutting force and improve finished material surfaces. Drilling is a common procedure in manufacturing, and there is an increased demand to shorten the tact time by reducing the cutting force, and by prolonging the tool's life. In this study, a new web shape was proposed based on the proposition to implement an additional cutting edge, complemented by experimental work. The results indicated that the cutting force decreased by more than 20%, and the circularity of the drilled holes was also improved.

1. Introduction

In the manufacturing industries of mechanical parts, molds, automobiles, aircraft, and electric appliances, the main issues include the acceleration of production, cost reduction, the optimization of employed technologies, productivity, and elicited environmental responses. For example, drilling is a commonly used procedure in the manufacturing of engine blocks and aerospace parts, and there is a considerable demand to shorten the tact time, increase precision, and minimize burr.

Numerous drilling studies have focused on surface integrity [1,2], deep holes [3,4], hard-to-machine materials [5–7], and new materials, including carbon fiber reinforced plastic (CFRP) [8–10]. Various processing methods have been proposed, classified in accordance with the hole size, hole depth, workpiece material, required accuracy, and other attributes. Additionally, other methods, such as press processing, electric discharge machining, electrolytic machining, ultrasonic machining, water jets, and lasers, are progressing. However, drilling is still a commonly used procedure, because it can be executed at lower costs. Drilling is often associated with problems, such as constraints on cutting conditions and tool breakage. Correspondingly, many problems remain to be solved.

The tool rake angle of the conventional tool is negative at the chisel edge that generates higher cutting forces. Therefore, web thinning is adopted as a method to reduce the cutting force during drilling. Conventional web thinning is performed from the center of the drill to the heel of the edge. The rake angle at the chisel edge becomes positive, and the cutting force effectively decreases. However, demands for highly efficient machining still exist. Therefore, a new drill type is required. Ko et al. proposed the use of new drill geometry to minimize burr [11], and Abele and Fujara reported twist drill design and optimization [12]. Armarego and Zhao developed predictive mechanics of cutting models for the thrusts and torques for these drill designs [13].

In this study, a new web shape was proposed based on the idea of implementing an additional cutting edge. The proposed web shape improves biting, cutting force reduction, and chip evacuation. The experimental results indicated that the cutting force decreased by more than 20% compared with a conventional tool, and the circularity of the drilled hole was good. The results also indicated that drilling can be done on the inclined face.

2. Method

2.1. Basic idea for new drill

Generally, the thrust force is large at the chisel edge, and a prior published study reported that it reached approximately 80% during drilling. For this purpose, web thinning and coating have been applied. However, as shown in Fig. 1, even if web thinning is applied, the rake angle changes in the region demarcated by A–C in Fig. 1b, and the rake angle is small at the chisel edge. This means that the sharpness still needs improvement. Here, the authors propose a new tool design to reduce the thrust force generated at the chisel edge, as shown in Fig. 2. With such a web shape, another cutting edge can be generated at the tip (Fig. 2c). The new edge extends from the chisel edge toward the outer periphery (red line in Fig. 2a and b), and it crosses the main lip. This edge is defined as the thinning edge.

This thinning edge has three characteristic features. The first is the bite on the workpiece. For example, in the case of drilling on an inclined surface, the tip of the drill easily slips. With the proposed drill, the actual cutting starts just below the drill center, so that it becomes difficult for the tip to slip, and the drill tip bites the surface of the material. It also will be possible to perform drilling at increased inclinations. The relation between the rake angle θ_1 at the main lip and the rake angle θ_2 at the thinning edge is important to prevent excessive penetration into the workpiece by setting $\theta_1 > \theta_2 > 0$.

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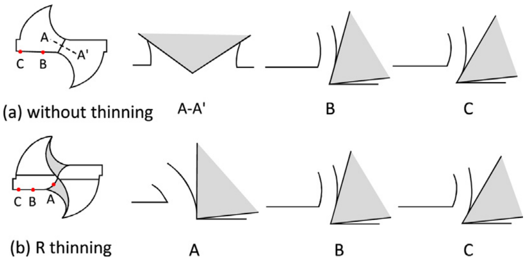

Fig. 1. Rake angle of cutting edge with/without web thinning.

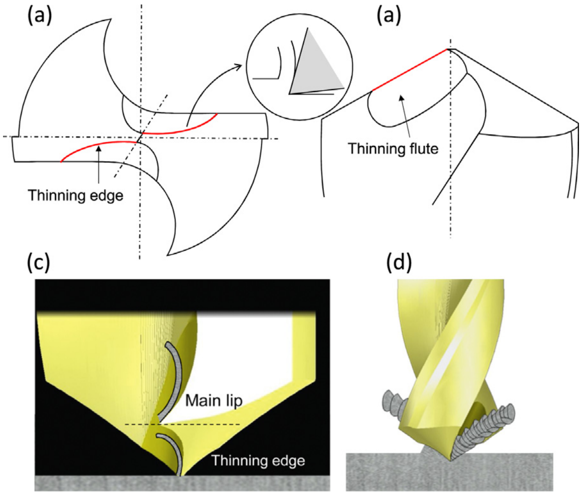

Fig. 2. New drill design to make additional cutting edge.

The second feature is the reduction of the cutting force. By forming a curved thinning edge, and by setting the rake angle $\theta_2 > 0$, it is expected that the edge sharpness will improve and that the cutting force will be reduced. Heat generation will also be decreased by reducing the cutting force. In this way, the cutting force can be reduced considerably compared with conventional drills, and drilling is expected to be performed with high efficiency. Moreover, reducing the cutting force improves the drilling accuracy. Furthermore, it is possible to prolong the tool's life.

The third feature is the evacuation of the generated chips. Forming a thinning flute along the twist of the drill enables the chip generated by the thinning edge to be removed smoothly.

2.2. Analytical model for new drill

Drilling based on the proposed thinning edge and main lip is considered to be a three-dimensional oblique cutting implemented by varying the tool's rake angle, cutting speed, and inclination angle. As shown in Fig. 3, the tip of the proposed drill consists of three parts: web, thinning edge, and main lip. Because it is difficult to formulate three-dimensional oblique cutting, the cutting edge is divided into many elements in the analytical model, as shown in Fig. 4. In each element, the thrust force dF_z and torque dM_z are calculated from the normal force dF_n and the frictional force dF_f, based on Eq. (1) [14].

Additionally, the normal force dF_n and the frictional force dF_f are expressed in accordance to Eqs. (2) and (3). The specific pressure (denoted by k_n for normal pressure, k_f for friction pressure) depends on the thickness of the uncut chip t_c, and the normal force dF_n and the frictional force dF_f are proportional to the uncut chip area dA_c.

$$\begin{Bmatrix} dF_z \\ dM_z \end{Bmatrix} = \begin{bmatrix} \dfrac{\cos\beta\sin p}{\cos\lambda} & 0 & -\dfrac{\cos p}{\cos\lambda} \\ 0 & r & 0 \end{bmatrix} \cdot \begin{bmatrix} \cos\eta_c\cos\alpha_n & -\sin\alpha_n \\ \sin\eta_c\sin\lambda + \cos\eta_c\cos\lambda\sin\alpha_n & \cos\lambda\cos\alpha_n \\ \cos\eta_c\sin\lambda\sin\alpha_n - \sin\eta_c\cos\lambda & \sin\lambda\cos\alpha_n \end{bmatrix} \begin{Bmatrix} dF_f \\ dF_n \end{Bmatrix} \quad (1)$$

$$dF_n = k_n dA_c \quad (2)$$

$$dF_f = k_f dA_c \quad (3)$$

where p is half of the point angle, β is the web offset angle, λ is the inclination angle, r is the radial distance, η_c is the chip flow angle, and α_n is the rake angle.

The elemental torque dM_z and the axial thrust force dF_z are summed up through the thinning edge and main lip. The total thrust force and torque for the thinning edge and the main lip can be calculated from Eqs. (4) and (5).

$$F_z = 2\left(\int_{r_0}^{A} dF_z + \int_{A}^{R} dF_z\right) \quad (4)$$

$$M_z = 2\left(\int_{r_0}^{A} dM_z + \int_{A}^{R} dM_z\right) \quad (5)$$

where r_0 is the boundary between chisel edge and thinning edge, A represents the boundary between the thinning edge and main lip, and R is the tool radius. The thrust force and torque in the region of the chisel edge are obtained from the slip line theory [14], but the influence is thought to be small compared with the proposed drill.

The proposed tool has an R-shaped edge at the center of the tip, so that a cutting edge with a positive rake angle is formed with respect to the chisel. With the proposed tool, the stress is concentrated at the edge, and the total cutting force decreased eventually. When the tip of the drill contacted the workpiece, the cutting force was generated by the thinning edge at first, and the bite to the workpiece improved.

The cutting edge of the new drill consisted of web, thinning edge, and main lip. This means that there are many parameters to be determined, such as the width of the web, curvature radius, and length of the thinning edge, considering the rigidity, cutting force, and accuracy of the finished hole. It is important to determine the optimal value of these parameters.

In the proposed drill, as the ratio of the thinning-edge length to the total length increases, the cutting force is reduced. However, the results of the preliminary experiments showed that the surface precision of the finished hole degraded when the length of the

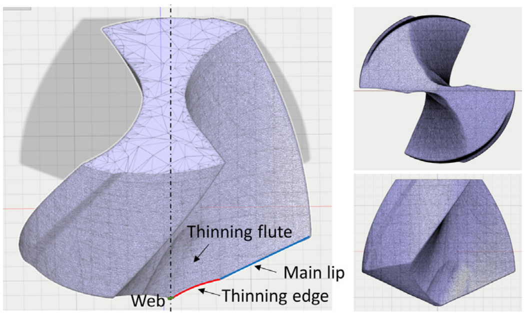

Fig. 3. Web, thinning edge, and main lip in the proposed drill.

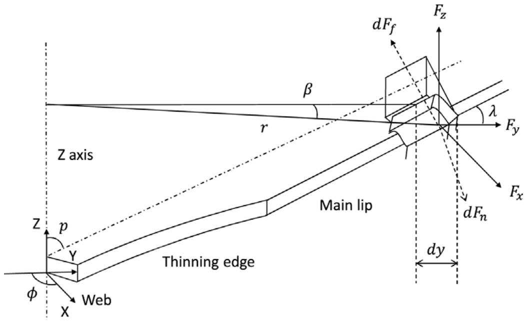

Fig. 4. Analytical model of cutting edge.

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