Design of intersecting holes for improvement of cleanability

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This paper presents an experimental study to prove that cleanability index can be used as reference for the design of intersecting holes. Cleanability index is defined as the sum of the burr heights along the periphery of intersecting hole. Burr height is function of exit angle and rotational cutting direction. And exit angle along periphery of intersecting hole is a function of inclination angle, offset distance and hole diameters, and the influence of each parameter on burr formation is analyzed. Using material Al6061, 16 cases of intersecting holes are experimented to measure burr height and segment length along the periphery and cleanability index in each case are calculated. Based on intersection of drilling hole in automotive engine, intersecting geometries were classified into five types of modeling. The experimental investigations at different locations at intersecting hole show that cleanability index is useful for evaluation of cleanability and can be used as an index for improvement of cleanability.

Keywords: Drilling, Burrs, Intersecting holes, cleanability index.

1. INTRODUCTION

Drilling is the most widely used machining process to produce holes quickly and at low cost. Intersecting drilled holes are common in industrial production. Burrs at intersecting holes are very popular in the production of automotive engines, transmission components, oil pump, and pressure components. Such burrs, located inside the components, are difficult to access and remove. An example for this is the burr formed by drilling operations in engine cylinder heads, where burr is located inside oil hole. These burrs can potentially lead to a complete engine failure during operation of the engine. In addition, it causes reduction of product life, affects dimensional tolerances and the assembly process, and can cause injury to the worker.

Previous studies of burr formation in drilling processes have been focused on burr formation mechanisms and influential factors on the burr size like exit angle, cutting conditions, and so on. Stein [1] showed experimental studies on burr formation at intersecting holes. Stein verified through fractional factorial experiments that on-axis hole, off-axis hole, exit angle, level of feed, and spindle speed influenced burr size and shape. However, it is proved that workpiece exit angle is most important factor.

Kim et al. [2] conducted experiment on the effects of drill type, cutting conditions and exit angle on burr formation in drilling. Moreover, the burr formation mechanisms of a twist drill and a gun drill in intersecting hole drilling as well as planar drilling were proposed.

Heisel et al. [3] developed a method of calculation of burrs on exit surface perpendicular to the drill axis, on which the burr value can be predicted for the short hole drilling of intersecting holes.

Ballou et al. [4] presents an experimental investigation of the burr formation for a new material, machinable austempered ductile iron by a factorial design which evaluate the effects of drill point angle, helix angle, feed rates and cutting speed at both curved and flat hole exit conditions.

Avila et al. [5] developed design rules for cleanability, assessment of cleanliness levels, and optimization of cleaning processes. Avila et al. [6] presented strategies to prevent solid particle contamination throughout the product development and manufacturing chain.

Garg et al. [7] conducted experimental investigation of mechanics of chip transport to build an effective chip optimization model that critically supports improving the cleanability of contaminant chips.

The increasing power density of engine as well as the complexity of parts in automotive production demand an entire control of burr formation especially in regard of intersecting holes. Regarding contemporary technology in

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automotive engine, high performance and more function are applied to engine. In that sense, the problems influenced by remained particles among engine oil, burrs, and chips after manufacturing become more important.

In automotive engine, the change of the design of intersecting holes is not easy because these intersections are based on the required functions and spaces of engine.

An experimental study was carried out to classify the intersecting geometry of drilled hole. The intersecting holes in engine can be classified into 5 models. It is well known that most serious burrs are formed at intersecting holes. To improve the cleanability in engine, it is very much necessary to prevent burr formation in machining and remove burrs after machining.

As a reference for cleanability, a new concept Cleanability Index (CI) is introduced by definition and calculation of CI in design of intersecting holes in engine, which can improve the cleanability of engine oil.

2. CLASSIFICATION OF GEOMETRY OF INTERSECTING HOLES

Burr formation in drilling process is affected by many factors as inclination angle, diameter of main and crossing hole, offset distance, and cutting conditions. In this research, the factors are related to the geometry of intersection holes.

Based on geometry of intersection of drilled hole in engine, the model of intersecting holes is classified into following five types: (1) closed intersection, (2) open intersection, (3) equal intersection, (4) window intersection, and (5) cone intersection as shown in Fig. 1.

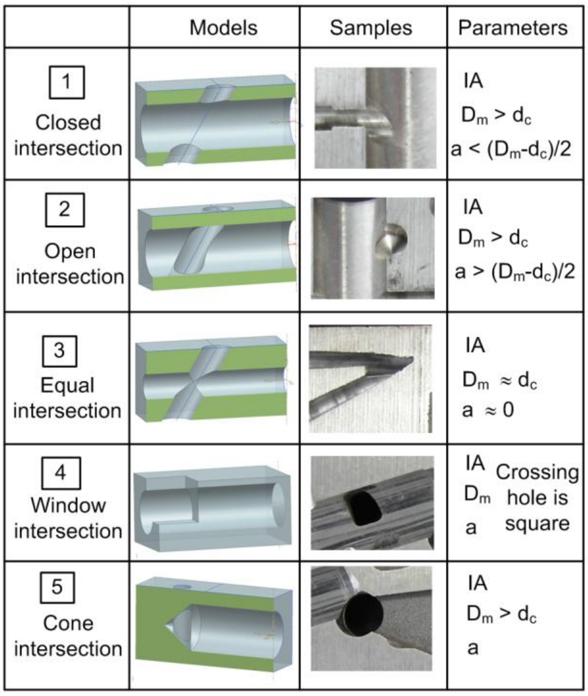


Figure 1. Modeling of intersecting hole in engine, (IA: inclination angle, a: offset distance, D_m: diameter of main hole, d_c: diameter of crossing hole in Fig. 2)

Kim et al. [2] introduced an equation to calculate exit angle along periphery at intersecting hole. This equation was utilized to evaluate exit angle related to cleanability index in this research. The exit angle at intersecting hole, ϕ, can be expressed by Eq. (1) and as shown in Fig. 2.

$$\phi = \frac{\pi}{2} - \tan^{-1}\left(\frac{\sin\omega(d_c \sin\omega - 2a)}{\cos IA\sqrt{D_m^2 - (d_c \sin\omega - 2a)^2}}\right) + \cos\omega \tan IA) \quad (1)$$

Where IA is the inclination angle, a is the offset distance, ϕ is the exit angle, ω is the angular position, d_c is the diameter of crossing hole, D_m is the diameter of main hole as shown in Fig. 2.

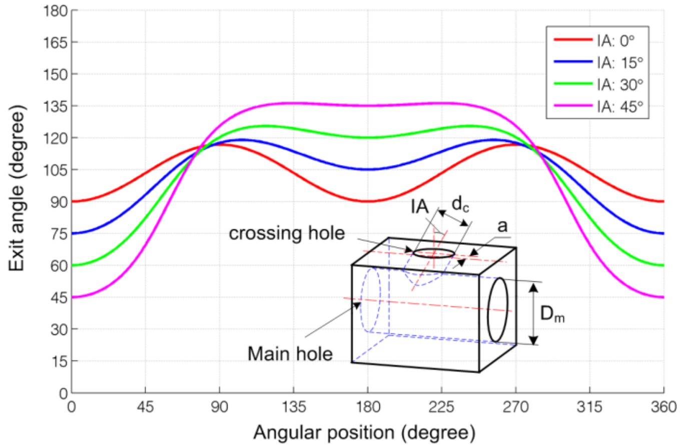


Figure 2. Exit angle along the periphery of intersecting holes with diameter of main hole (D_m) 20 mm, diameter of crossing hole (d_c) 9 mm, offset (a) 0 mm, and inclination angle (IA) 0°, 15°, 30°, and 45°.

From Fig. 2, it is observed that the exit angle covers more wider as inclination angle, IA, increases. When IA is 0°, exit angle changes from 90°to 120°, however, when IA is 45°, exit angle covers from 45° to 135°.

3. DEFINITION OF CLEANABILITY INDEX AND EXPERIMENT

Based on experimental results as shown in Fig. 3, model 2 shows that the largest burrs are formed when increases offset distance, a, and inclination angle, IA. Model 1, closed intersection, is important for design and improvement of cleanability in engine. This is because the most cases of intersecting hole is classified into the model 1. Thus, it will be used to evaluate level of cleanability index. Furthermore, the other models, 2, 3, 4, and 5, have completely different characteristics and operations. Therefore, these models must be treated separately in other parts.

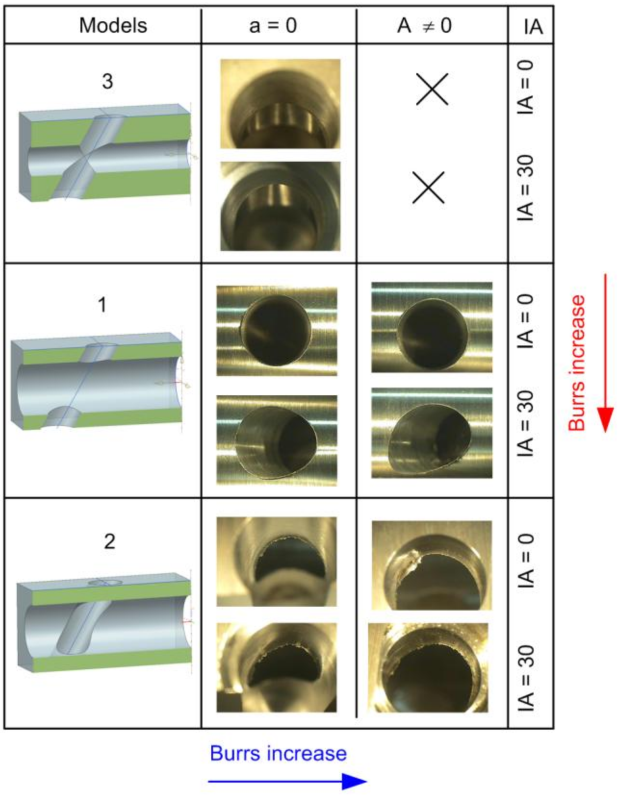


Figure 3. Examples of burr at intersecting holes of models 1, 2, and 3.

In this work, the cleanability of the model 1 is considered by changing the related parameters. The experiments were conducted using material AL6061 with the geometrical changes: diameter of main hole, 20 mm, diameter of crossing hole, 4 and 6 mm, inclination angle, 0°, 15°, 30°, 45°, and offset distance, 0 and 4 mm. After experiments, average height of burr are measured at 8 points of angular position along periphery on exit surface as show in Fig. 4.

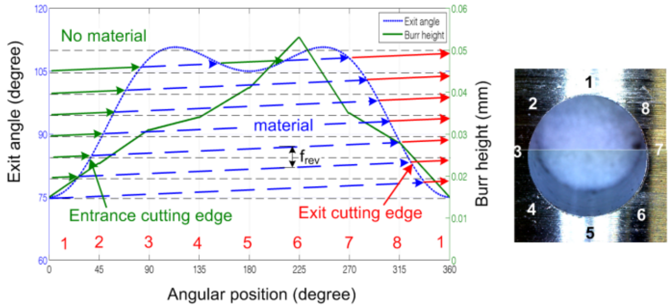
New concept of Cleanability Index is introduced as a reference for design of intersecting holes considering the amount of burr formation along the periphery.

Cleanability index is defined as in Eq. (2), which calculate the summation of burr heights at each point. Burr height is determined according to exit angle and direction of cut, entry or exit when material and cutting condition is decided.

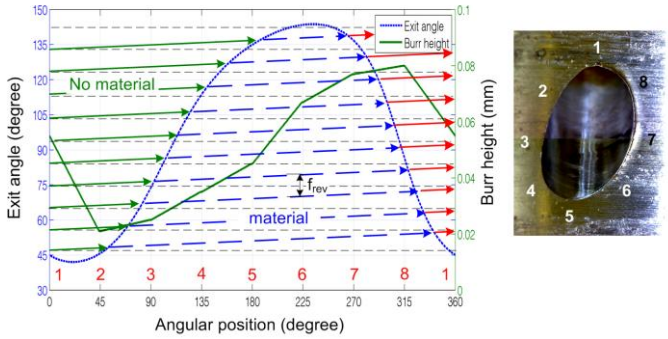
$$CI = \int_0^l h(\phi) w \Delta l = \sum_{i=1}^{n} h_i(\phi) w \Delta l_i \quad (2)$$

$$\phi = func(IA, a, D_m, d_c) \quad (3)$$

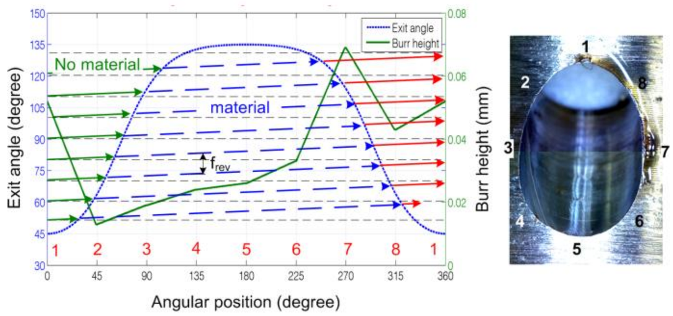
Where h_i is the height of burr at a point along periphery, *IA* is the inclination angle, *a* is the offset distance, D_m is the diameter of main hole and Δl is the length of segment of around measured point, *w* is the coefficient dependent on direction of cutting edges as tool enters or exits.



(a)



(b)



c)

Figure 4. Burr height according to exit angle with (a) case of number 7, (b) case of number 14, (c) case of number 15 in table 1.

Cleanability index is introduced to design the intersecting holes properly to improve the cleanability by reducing the burr formation. Cleanability index can be used as a reference for the design of intersecting holes.

Along the periphery of intersecting hole, burr heights, h_i, are measured at each point, *i*, at n points in this case and the segment length around point, *i*, Δl_i, can be calculated.

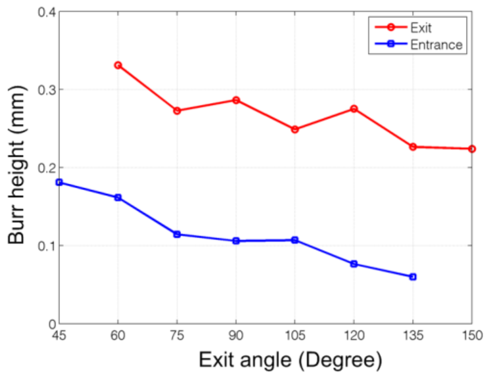


Figure 5. Burr height according to exit angle when tool enters and exits

Table 1. Results of cleanability index

No.	IA (°)	d_c (mm)	a (mm)	CI
1	0	4	0	0.3636
2	0	4	4	0.3694
3	0	6	0	0.3922
4	0	6	4	0.3922
5	15	4	0	0.4465
6	15	4	4	0.4197
7	15	6	0	0.4429
8	15	6	4	0.4516
9	30	4	0	0.4546
10	30	4	4	0.5139
11	30	6	0	0.5355
12	30	6	4	0.5772
13	45	4	0	0.7073
14	45	4	4	0.7513
15	45	6	0	0.7520
16	45	6	4	0.7663

The burr height is a function of exit angle, ϕ and the coefficient of cutting direction w. The exit angle can be calculated using Eq. (1) as function of *IA*, *a*, D_m, d_c. The exit angle is calculated and shown in Fig. 4 with the picture of intersecting hole in the case of 7, 14 and 15 in table 1. Moreover, measured burr heights are illustrated together. When IA is 15°, the exit angle covers from 75° to 110° as in Fig. 4(a) and when IA is 45°, it covers from 45° to around 135° as in Fig. 4(b) and (c). In addition, it is found that burr height is larger along the exit side of rotation, points 1, 7, with small exit angle as shown in Fig.4 (b) and (c). In Fig. 4, the path of cutting edge is illustrated as drill rotates during exit. At points, 2, 3, 4, and 5, tool enters and at 5, 6, 7, 8 and 1, tools exits and produces larger burr than when tool enters.

Fig. 5 shows the burr height at different exit angles when tool enters and exits during rotation on exit surface. The ratio of burr height at exit edges and entrance edges is defined as *w*. If the ratio can be obtained by the ratio of the average value, CI can be calculated with exit angle calculation as in Eq. (1) and the burr formation information at different exit angle at *a* given cutting conditions with exit and entry height ratio, w.

The cleanability index is calculated as in table 1 and displayed in Fig. 6 according to each case. It is evident the most prominent factor is inclination angle, *IA*, and then offset distance, *a*, influences on burr height. And as diameter increases, the length increases, which increase CI value as in Fig. 6.

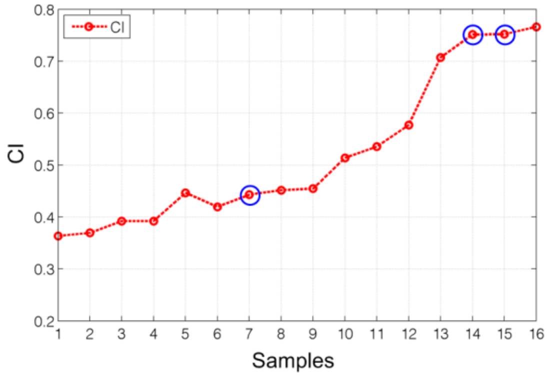


Figure 6. Cleanability index calculation at each case

From the Fig. 6, it can be concluded that CI can be used as a design reference value for improvement of cleanability at intersecting holes. This will help the design considering cleanability.

4. CONCLUSIONS

Automotive engine includes many intersecting holes, which induce many problems in cleanability. Intersecting holes are classified into five models in engine.

The exit angle along the periphery of intersecting hole is calculated using the previous work by Kim [2]. When the material and cutting condition is decided, burr height is a function of exit angle and cutting direction, from which the cleanability index can be calculated.

To design complicate parts including many intersecting holes, concept of cleanability index is introduced as a quantitative reference. When inclination angle, offset distance and diameter of crossing hole increase, the cleanability index increases.

From this work, it is proved that cleanability index can be used properly for the design of intersecting hole to improve the cleanability.

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