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Numerical and experimental investigation of the discontinuous dot indenter in the fine-blanking process

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ABSTRACT

The fine-blanking process has been widely applied in industries to produce clean-cut surface parts. The V-ring indenter blank holder, which is an essential part of the fine-blanking tool, is notably important in increasing the cutting surface quality of blanked parts. Because the V-ring indenter is difficult to manufacture, it is difficult to ensure the machining accuracy, and the cost is notably high. In this study, a new discontinuous dot indenter blank holder is presented. The discontinuous dot indenter blank holder can improve the quality of the fine-blanked surface, which is identical to that of the V-ring indenter, but the manufacture process is notably easy, and the cost is notably low. The hydrostatic stress, material flow and quality of the fine-blanked surface in the fine-blanking process were analyzed to reveal the discontinuous dot indenter mechanism. To obtain a larger burnished zone, the finite-element (FE) simulation and ANOVA technique were applied to optimize the discontinuous dot indenter parameters, i.e., dot diameters, fillet radius, distributions, positions and heights. Next, these optimal parameters were applied to fine-blank a spur gear, and the experiment results have a good agreement with the FE simulation results. Moreover, the results also indicate that the discontinuous dot indenter can be used in the fine-blanking process to obtain almost full clean-cut surface parts.

1. Introduction

Compared with the conventional blanking process, the fine-blanking process has many advantages, such as the ability to produce high dimensional precision, clean-cut surface parts, and notably high efficiency. The fine-blanking process has these advantages because of the following special characteristics: a small clearance between the punch and the die, a high pressure on the blank holder, and a high pressure on the counterpunch [1–3]. Studies on the fine-blanking process are a hot topic in recent decades. Lee et al. [4] studied the deformation theory of the fine-blanking process using an analytical method. Chen et al. [5] investigated the formation and propagation of the shear band in the fine-blanking process. Both optical microscopy and SEM were applied to observe the cross-section surface microstructure of the fine-blanked specimens. Li and Fan [6] investigated the plastic state of material in the shearing zone under the condition of negative clearance, and Tanaka and Hagihara [7] studied the fine-blanking process with the high tensile strength steel.

As an essential part of the fine-blanking process, the blank holder generates hydrostatic stress to improve the material ductility. As a result, it impedes the fracture initiation and propagation. Today, the V-ring indenter is widely used in the fine-blanking process, and many studies have been performed. Thipprakmas [8] revealed the mechanism of the V-ring indenter in the fine-blanking process. He also investigated the effect of the V-ring indenter parameters, i.e., the V-ring indenter angle, height and position, on the forming process using the FE simulation, Taguchi method and ANOVA technique [9]. Because of the important rule of the V-ring indenter, Elyasi also studied the parameters process, and the results shows that the height, position and angle of the indenter have a major influence on the fine-blanking process, followed by tip radius of the V-ring indenter [10]. Kwak et al. [11] investigated the effect of the V-ring indenter on the sheared surface during the fine-blanking process of pawl using FE simulation and experimental methods.

Although the V-ring indenter has been widely used, the fabricating cost is notably high and increases the total cost of the fine-blanking tool because the V-ring indenter requires notably high dimensional accuracy, and the V-shape is notably complicated in some cases such as for gear parts. To resolve these problems, Wang et al. [12] presented a new technique named hydromechanical fine blanking, and the effect of the fluid cavity shape on the

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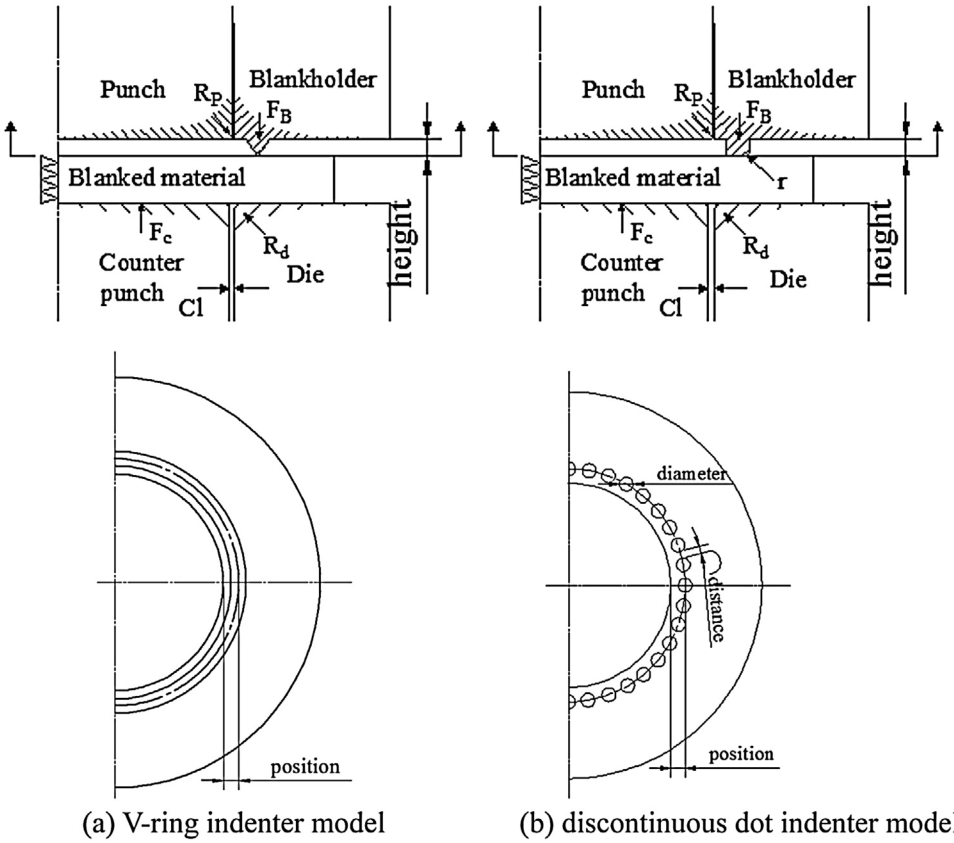

Fig. 1. Schematic diagrams of the V-ring indenter and discontinuous dot indenter.

shear-zone length has been investigated by Huang et al. [13]. However, the carving works on the workpieces also increase the cost and time. Therefore, Wang [14] proposed another method, a tough on the die was used to replace the V-ring indenter. In this approach, the workpiece was compressed by the blank holder to increase the hydrostatic stress in the shear zone near the area of the knife edge of the die. Therefore, the length of the burnish was large, and the thickness of the blank could approach 25 mm. This blank holder is notably good for the thick-plate (>16 mm) fine-blanking process.

In this paper, a new blank holder named discontinuous dot indenter was proposed, which has not been studied. A series of discontinuous dot indenters on the blank holder was applied to replace the V-ring indenter. When the discontinuous dot indenter penetrates the workpiece, the workpiece around the shear zone is in a three-hydrostatic stress state. Therefore, the discontinuous dot indenter blank holder can have identical function to that of the V-ring indenter. In the industry, the V-ring indenter is always machined by the milling or electric-spark process. To guarantee its machining accuracy, a high-precision CNC milling machine is required for the two fabrication processes, and the cost is high. However, the discontinuous dot indenter is easily manufactured using the electric-spark process. The fabrication of the tool-electrode is notably easy: only a series of holes must be drilled on the tool-electrode, which can significantly reduce the manufacturing cost.

In this study, the effect of process parameters such as the discontinuous dot indenter diameters, fillet radius, distributions, positions and heights on the shearing surface was investigated. The FE simulation method was used to predict the cutting surface quality of the fine-blanked parts [15]. The orthogonal array and ANOVA techniques were performed to optimize these parameters. Finally, a spur gear was successfully fine-blanked with a perfect clean-cut surface using the discontinuous dot indenter.

2. FE simulation model

The FE simulation models in this study are classified into two cases as shown in Fig. 1. To simplify the model and reveal the mechanism, only a circular plate with the diameter of 20 mm was used as the workpiece. Fig. 1a shows the V-ring indenter blank holder model. Fig. 1b shows the discontinuous dot indenter blank holder model. The V-ring indenter angle was 90°, the distance from the punch side was 3.2 mm, and the height was 0.9 mm. The discontinuous dot indenter has five parameters: diameter, fillet radius, distribution (distance between the dots), position and height, which affect the quality of the fine-blanked parts. The discontinuous dot indenter has identical position and heights to the V-ring indenter; the fillet radius (r) and distance between the dots were 0.4 mm and 0.65 mm, respectively. The diameters of the dot were changed from 1.0 mm to 1.8 mm.

In this study, AISI-1035 with a thickness of 4.0 mm was used as the blanked material. The material properties are shown in Table 1.

Table 1
Material parameters of AISI1035.

Parameter	Value
Tensile strength	455 MPa
Yield strength	325 MPa
Elongation	32.1%
Elastic modulus	174 GPa
Poisson's ratio	0.3
σ	$718\varepsilon^{0.157} + 57.31$ MPa