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Optimum blank shape design by sensitivity analysis

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Abstract

A method of blank shape design based on sensitivity analysis for the non-circular deep drawing process has been proposed. By assuming the final deformation shape to be a drawn cup with a uniform trimming allowance at the flange, the corresponding initial blank which gives the final shape after deformation has been found. With the aid of a well-known dynamic explicit analysis code PAM-STAMP, shape sensitivity has been obtained. To obtain the shape sensitivity numerically, a couple of deformation processes have been analyzed. In order to validate this method, deep drawings of a square cup, a clover shaped cup and an L-shaped cup have been chosen as the examples. In every case converged results have been obtained only after a few times of modification. With the predicted optimal blank, both computer simulation and experiment are performed. Excellent agreement is noted between simulation and experiment in every case. Through the investigation, the proposed systematic method of optimal blank design is found to be very effective in the design of a deep drawing process.

Keywords: Optimal blank design; Sensitivity analysis; Deep drawing

1. Introduction

In order to optimize sheet metal forming processes, the effects of a considerable number of process parameters are evaluated experimentally or analytically. Basically the optimization processes are based on the trial-and-error method owing to the inherent characteristics of metal forming processes. Because of the nature of the trial-and-error method, however, a significant number of iterations are usually required to optimize the processes.

In general, sheet metal forming products in modern industries have a complicated shape and the forming process consists of several successive operations until the final shape is formed. Because of the complexity, the use of 3D CAD systems is increasing in the design of sheet metal product. With 3D CAD data, the die surface can be machined by CAM and the deformation process can be analyzed by a CAE technique.

In the deep drawing processes, the use of an optimal blank not only saves the material but also it may reduce the occurrence of defects e.g. wrinkling, tearing. However, it is not easy to find the optimal blank because of the complexity of material behaviour. Several methods have been developed to design the optimal blank and there are many different approaches to find the optimal blank. Among the methods, the slip line field method [1–5], the geometric mapping method [6,7], the trial-and-error method based on the FE method [8–10], the inverse method [11–13], ideal forming [14], backward tracing [15], the volume addition/subtraction method [16], and the analogy method [17,18] are notable.

In this study, a systematic method based on sensitivity analysis has been proposed to find the optimal blank for the deep drawing of arbitrary shape cups described by a 3D CAD system.

2. Theoretical foundations

Let **X** represent a position vector of a material point located at the outermost node of an initial blank before deformation and **x** represent a position vector of the material after final deformation.

With the initial blank defined by **X**, the deformation process is analyzed by Pam-Stamp®. Fig. 1 shows the movement of the node during deformation. Fig. 2 describes details of Fig. 1 to explain the concept of the error correction method. If **x** does not lie on the target contour $\mathbf{x}_T$, the position of the material point before deformation **X** should be moved

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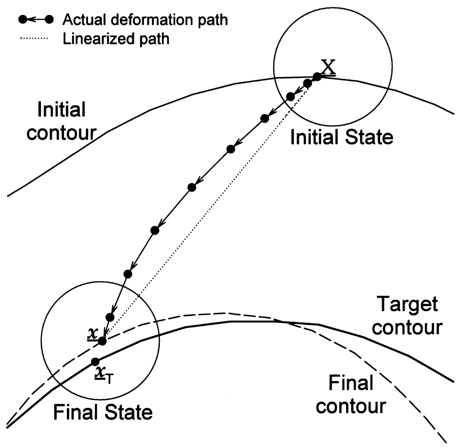


Fig. 1. Movement of an outermost node.

in order to make the deformed contour coincide with the target contour $\mathbf{x}_T$. By introducing the concept of shape sensitivity, the shape of the initial blank, i.e. $\mathbf{X}$, can be changed. The shape sensitivity has been derived numerically by considering two blanks, the original blank and an offset blank.

The offset blank shape has been determined from the information of deformation analysis with the initial blank defined by $\mathbf{X}$,

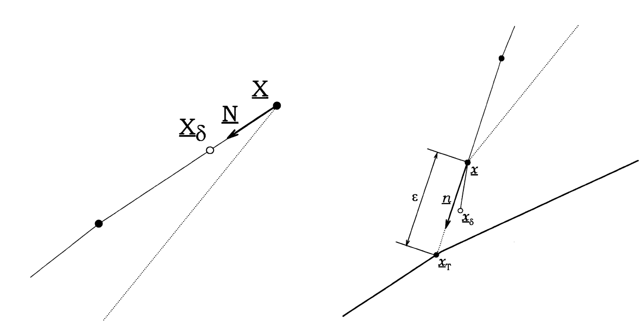
$$\mathbf{X}_\delta = \mathbf{X} + \delta\mathbf{N} \tag{1}$$

where $\mathbf{X}_\delta$ represents the position vector of a material point located at the outermost node of an offset blank before deformation. $\mathbf{N}$ is the unit vector in the deforming direction at the first step. δ is the amount of offset. With the offset blank defined by $\mathbf{X}_\delta$, the deformation process has been analyzed again to obtain, $\mathbf{x}_\delta$, the material point position after deformation for the offset blank.

The sensitivity for the deformation at each node is defined as

$$S = \frac{|\mathbf{X}_\delta - \mathbf{X}|}{|\mathbf{x}_\delta - \mathbf{x}|} \tag{2}$$

If $\mathbf{x}$, the coordinates of the outermost node after deformation coincide with $\mathbf{x}_T$ which lies on the target contour, there is no need to move the corresponding node of the initial blank.



(a) (b)

Fig. 2. Details of Fig. 1: (a) initial state; (b) final state.

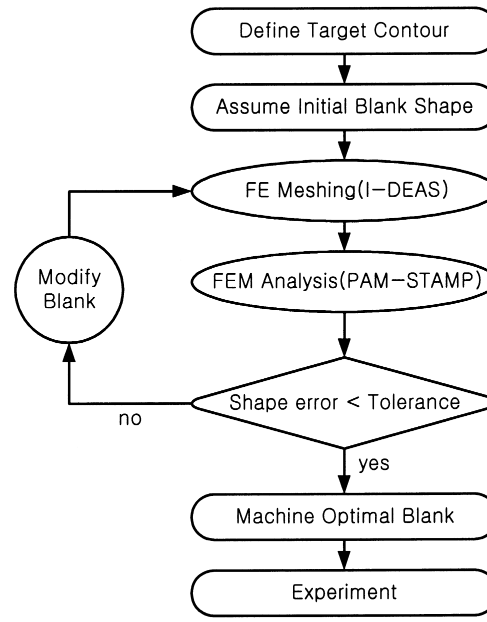


Fig. 3. Flow chart for optimal blank design.

Table 1
Material property of blank

Property	Value
Young's modulus, E (MPa)	2×10^5
Poisson's ratio, v	0.3
R-value	1.38
Stress–strain relation, σ (MPa)	$514(0.001+\varepsilon)^{0.2}$
Coulomb's coefficient of friction, μ	0.24 (punch per sheet)
	0.12 (punch per sheet)

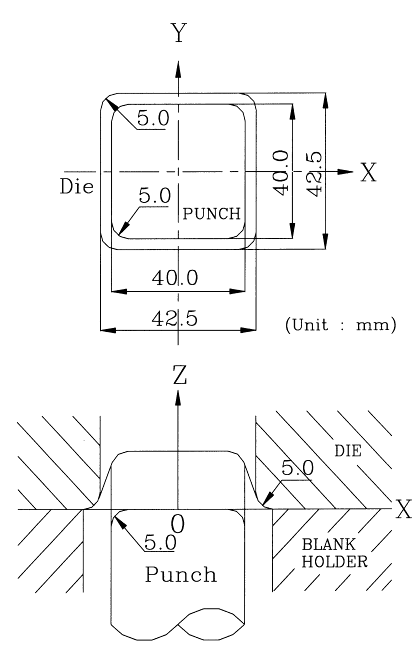


Fig. 4. Die geometry for square cup deep drawing.