FEM STUDY TO VERIFY THE EFFECT OF EMBOSSING AND WAVE SHAPES ON FORMABILITY OF STAMPING PROCESS FOR MULTI-HOLE ETCHING METAL FOIL USING SUS316L MATERIAL

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Abstract

In current study, to predict ductile fracture and spring-back in making embossing shape using multi-hole etching metal foil of SUS316L material, FEM simulation was adopted. Ductile fracture criterion of forming limit diagram (FLD) and stress-strain curve based on experimental data were first input to ABAQUS/Explicit finite element code to predict failure and spring-back occurrences. Several simulations were then performed with the dimension changing of etching holes in order to simulate and investigate press formability of final product after forming process. The better case was obtained by utilizing simulation results. FEM simulation results were finally confirmed by the corresponding experiment. The FEM predictions were in good agreement with experimental result.

Keywords: Ductile fracture, FEM simulation, Metal foil, Spring-back, Stamping

Introduction

Recently, sheet metal forming processes was applied in many industrial products due to the decreasing cost and time and improving quality of forming processes. However, there are two big phenomenons happening after forming processes, namely, spring-back and fracture occurrences. Ductile fracture frequently occurs in the critical area when subjected to serious strain during the forming process and is found to be prone to internal or superficial microdefects owing to excessive tensile stress. This initial damage and its growth then cause quality problems, such as necking and fractures, owing to ductile tearing of the sheet. Spring-back normally occurs when sheet element moves through the punch and die because of material elements experience elastic unloading and spring-back when sheet parts are removed from tools after forming. Therefore, spring-back and ductile fracture predictions based on sheet metal formability and tension-compression behavior are the most important goals of the FEM simulation. Accordingly, in order to understand and estimate formability it is necessary to analyze the spring-back and failures occurring as a result of sheet metal forming. The formability of sheet metals is often evaluated using a strain analysis based on the concept of Forming Limit Diagram (FLD), which was an effective tool to predict the defects such as necking, fracture, etc occurred during the sheet metal forming operations and related with pairs of principal limit strains (Major Strain, ε_1 and Minor Strain, ε_2), originally introduced by Keeler [1] and Goodwin [2].Until now, FLDs have been widely accepted as a useful measure of the formability of sheet metal. The previous researchers [3, 4] shown that the effects of tension-compression tensile curves on spring-back are mainly significant due to the reverse loading phenomena after the tools move far from the sheet parts.

Nowadays, finite element method (FEM) simulation, an effective tool for an understanding of the physical processes and describing the material phenomena in continuum phenomenological plasticity, was currently applied to clarify the forming characteristics, predict spring-back and improve the forming process. After the pioneers work of (FEM), It has been successfully became the basis of spring-back compensation and fracture prediction methods by many research works [3-7]. Hassan et al. [8] investigated the effect of bulge shape on wrinkling formation and strength of stainless steel thin sheet by experimental test and FEM simulation, then showed that embossing and restoration technique can increase the strength, the flexural deflection and decrease the failure risk of thin sheet materials. Mai et al. [9] proposed the electrical-assisted embossing process to fabricate micro channels on 316L stainless steel plate and demonstrated the feasibility and advantages of this process by verifying the effect of process parameters on formability using experiments and FEM simulations.

In this study, In order to predict material fracture and spring-back then improve the press formability of embossing and wave shapes using multi-hole etching metal foil of SUS316L material, the FEM simulations are coupled experimental data. Among many ductile fracture criterions, the forming limit curve (FLC) criterion shows in good predictions at both right and left-hand side of FLDs. So that, FLDs data applied for numerical analysis to predict ductile fracture are quite relevant. To simulate the spring-back, the nonlinear hardening model developed by Amstrong– Frederick [10] and then Chaboche [11] was adopted. In FE simulations, the changing parameters of embossing shapes were used to verify their effect on ductile fracture and spring-back predictions of final product after forming operates. The numeric simulations can reveal the most important variable to improve the ductile fracture and spring-back of embossing shape with multi-hole. The selection case of FEM simulation was finally confirmed by an experimental result.

Material and Experimental Setup

Table 1. Mechanical Properties of Tested Material

Material	SUS316L
Density (ρ, kg/mm^3)	7.8e-06
Young's modulus (E, kN/mm^2)	210
Possion's ratio	0.3
ε_0	0.000177
K (MPa)	864.2
n-value	0.195

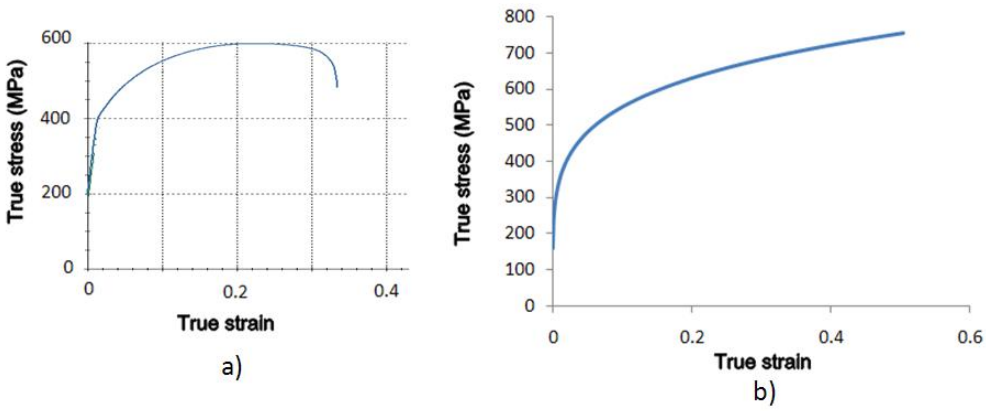

Figure 1. Stress-strain curves based on (a) experimental data and (b) Swift's hardening law

The tensile tests of 0.1 mm thickness SUS316L material were carried out for the tensile specimens cut from the sheet in parallel to the rolling direction whose mechanical properties are given in Table 1. Figure 1(a) shows the flow stress curve of tested material. To fit flow stress data, Swift's equation (Equation 1) [12] is implemented using least square fitting method to determine the equation parameters which were also listed in Table 1 and depicted in Figure 1 (b).

$$\sigma(\varepsilon) = K(\varepsilon_0 + \varepsilon)^n \quad (1)$$

where K is the plastic coefficient, n is the work-hardening exponent, and σ, ε, and ε_0 are the equivalent stress, equivalent strain, and offset strain, respectively.

Figure 2. Schematic of experimental FLD

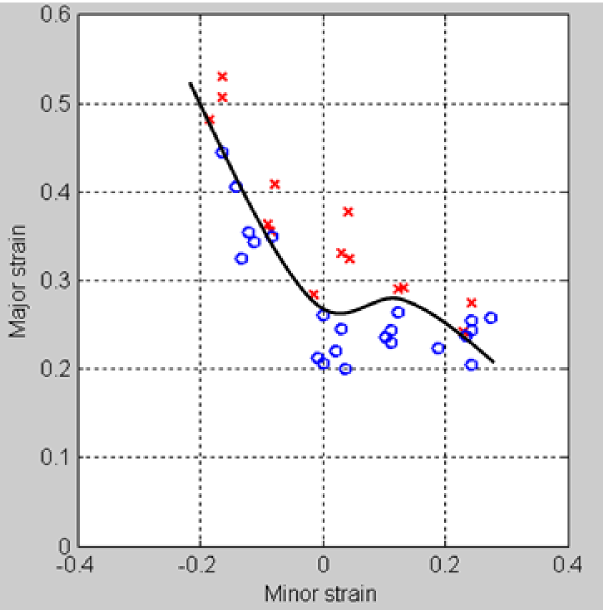

Figure 3. Experimental data of FLD

In order to determine forming limit curves, experimental data resulting from the punch stretching tests proposed by Hecker [13] was conducted. To take experiment, specimens are prepared from sheet metal, and subjected to different amounts of initial shape to the punch stretching test using hemispherical punch with punch radius of 50.8mm, as shown in Figure 2. Before stretching test of the specimen circle grids of 2.54mm diameter are first marked on the surface of the test specimen. After setting and clamping tightly the specimen by clamping bead to prevent the material draw-in during the test punch travels at a constant rate of 10mm/min until the punch load sensed a preset load drop, typically on the order of 1~10%. For FLD determination, it is most desirable to stop the test of incipient necking. Circle grid analysis was used to measure the major and minor strain of the deformed circles on the deformed specimens. A camera was used to capture images of the deformed circles near the fracture while the in-house developed Grid Analyzer software calculated the engineering major and minor strains of the deformed circles. Data was plotted on major and minor strain axes and thus the forming limit diagrams were estimated as the boundary curve (solid line) between the "safe" strain (the circle symbol)) and "fail" strain (the cross symbol (×)) as shown in Figure 3

Finite Element Simulation

In current study, the ABAQUS version 6.10-1 [14] was use in this work to simulate the stamping process of multi-hole etching metal foil. This software can provide elastic-plastic and rigid-plastic simulations of metal forming for a case of large deformation, significantly reducing the cost and time involved in tool and die design.

The FEM model for embossing and wave shape with multi-hole etching metal foil were depicted in Figure 4, here only a quarter of the specimen was model. The blank was modeled using shell element (S4R) and rigid surface element (R3D4) was used to model the die and punch. The die was fixed in all directions and let the punch move in the vertical direction. The coulomb friction was adopted for friction behavior and we assumed that the friction coefficient between the blank and the die/the punch is 0.1.

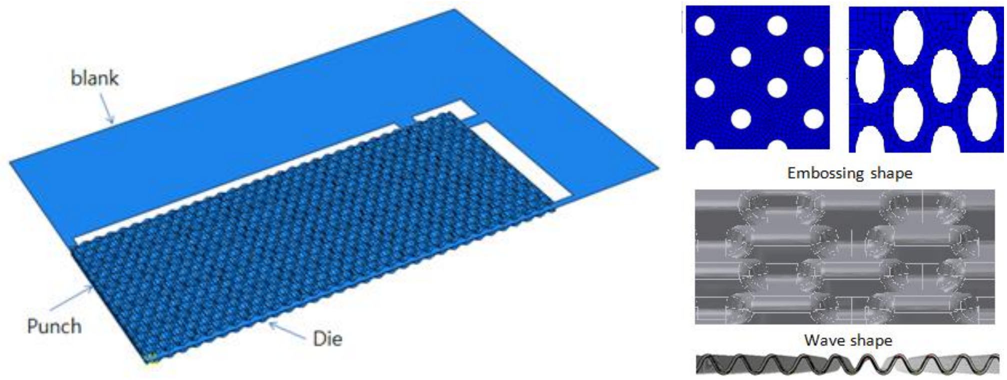

Figure 4. Finite element model for forming simulation

In order to verify the ductile fracture criterion based on FLC failure criterion, FLC data obtained from experimental results were implemented into ABAQUS/Explicit to simulate the stamping process. Here, when the FLC failure criterion at an element, which was defined by the ratio of the major strains (ε_1) and the FLC values at the same point for the minor strains (ε_2), reach to unit value. Then the element could be deleted following softening behavior of damage model or remained to see the evolution of failure.

In order to simulate spring-back, the stamping process was performed in two steps with Abaqus/Explicit and Abaqus/Standard. In the first step of the analysis the punch was moved follow vertical direction to obtain deformed shape, the spring-back analysis was then simulated with Abaqus/Standard. Here, the results from the forming simulation in Abaqus/Explicit are imported into Abaqus/Standard, and a static analysis calculates the spring-back. During this step an artificial stress state that equilibrates the imported stress state was applied automatically by Abaqus/Standard and gradually removed during the step. The displacement obtained at the end of the step was the spring-back, and the stresses give the residual stress state.

Results and Discussion

Figure 5 shows the FE simulation predictions of ductile fracture for stamping process of embossing and wave shapes with 0.6 mm of the depth shape when changing the hole - dimension. As shown in Figure 5 (a, b, c) for the case of embossing shape when the hole dimension increase from R = 0.11mm to R = 0.2 mm then the ductile fracture value also increase. In FE simulation of forming process, when the FLC ductile fracture value (FLDCRT) approached 1.0 then condition of failure occurs. The failures only appeared for case (c) (FLDCRT=1.345) due to the satisfying condition of FLC ductile fracture criterion. In case of wave shape with ellipse hole (Figure 5 (e, f, g)), only minor dimension of ellipses was modified. After deformation, the major dimensions of ellipse holes were not changed but contrary to the case of embossing shape, ductile fracture value increase when the minor dimensions decrease and the safety condition only satisfied for case (e) (FLDCRT=0.956).

To validate the agreement between simulation and experimental results, cracked case (f) and safe case (e) were performed as shown in Figure 6.

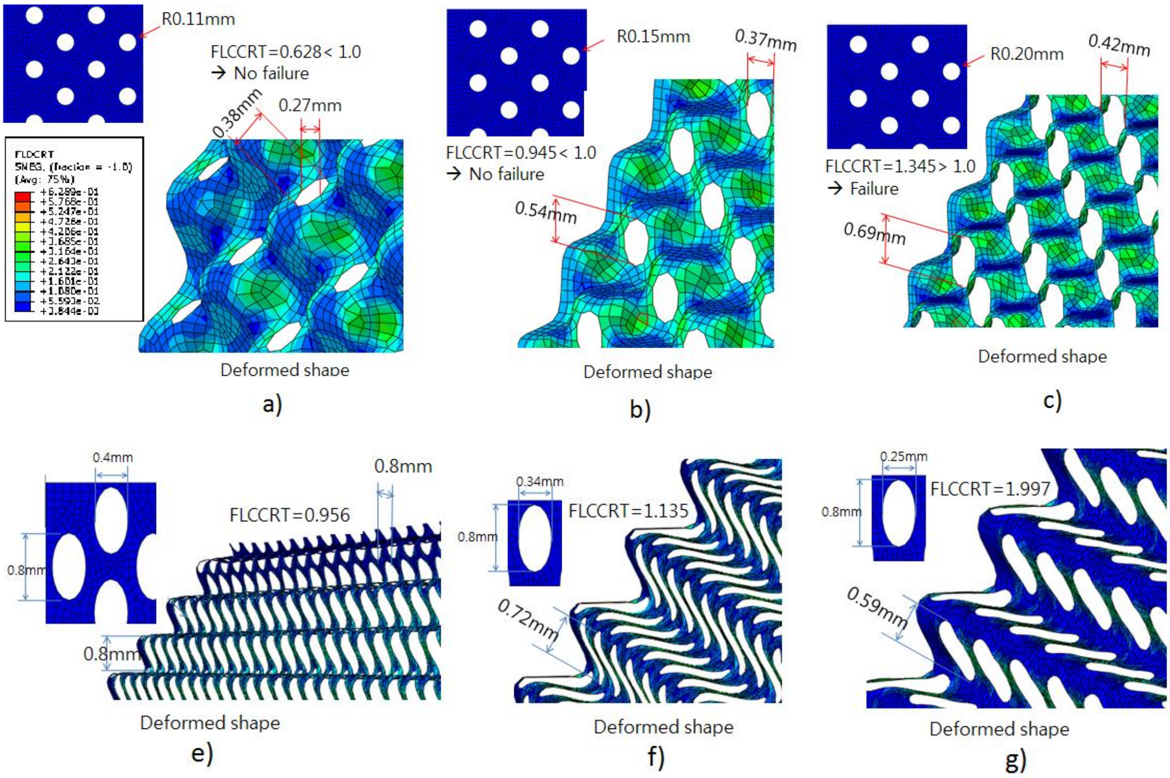

Figure 5. Deformed shape in FE simulations for the changing of hole dimensions of embossing shape (a, b, c) and wave shape (e, f, g)

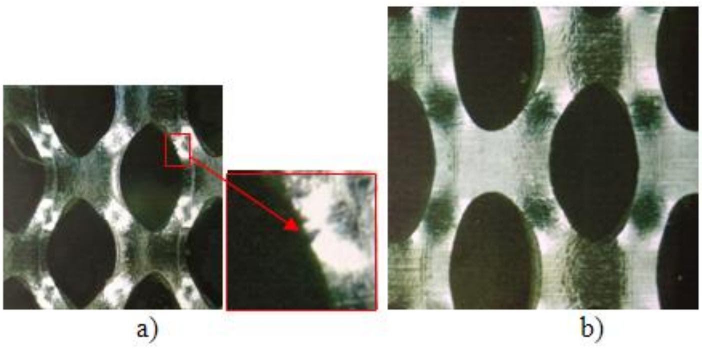

Figure 6. Experimental results for a) cracked case (f) and b) safe case (e)

Figure 7 presents the simulation procedures to predict spring-back of embossing and wave shape after stamping. Here, stamping process was first performed with Abaqus/Explicit, after deleting the rigid die and punch, the deformed blank shape was then imported into Abaqus/Standard. Finally, the von-Mises residual stress state was statically calculated and gives the spring-back predictions. As the results of FEM simulations, there are no effects of changing hole - dimension on spring-back predictions. As shown in Figure 7, the spring-back value of embossing shape has the smaller value of 2.58^o (Figure 6(a)) when comparing with3.65^{o}of wave shape (Figure 6 (b)). This means that embossing shape gives the better condition for spring-back behavior.

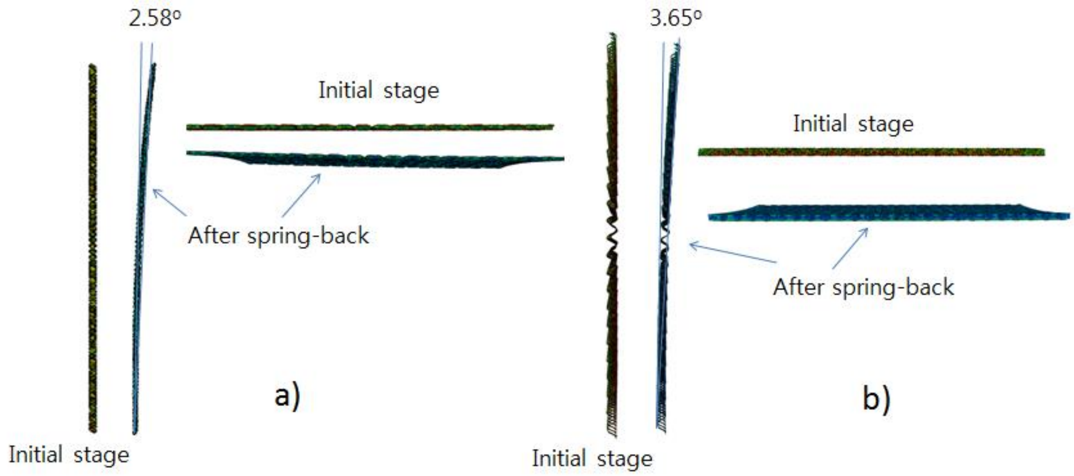

Figure 7. Spring-back prediction in FE simulations for a) embossing and b) wave shape

From the above discussion with simulation results, embossing shape for multi-hole etching metal foil using SUS316L material was decided to design and fabricate. The die and punch of embossing shape are shown in Figure 8 (a). The blank shape (Figure 8 (b)) of tested sample was deformed then trimmed as shown in Figure 8 (c) to confirm FEM predictions. The trends of the failure site and spring-back predicted in this study were in good agreement with those in the actual product.

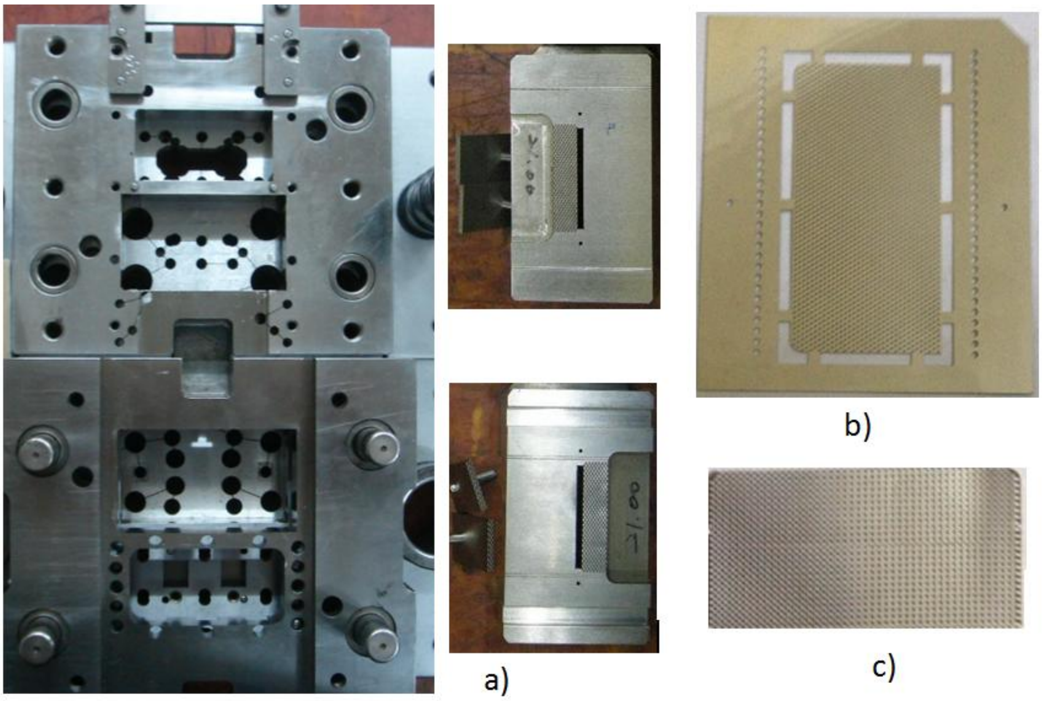

Figure 8. Experiment for actual product a) tools for stamping, b) blank shape and c) final product after forming and trimming.

Conclusions

To predict the spring-back and fracture of embossing and wave shapes in stamping process of multi-hole etching metal foil using SUS316L material, computational modeling was applied to verify the effect of hole dimensions on ductile fracture and spring-back using finite element simulations. ABAQUS version 6.10 with strain-stress curve and FLC ductile fracture criterion values based experimental data of tension and FLC tests were used for the simulation. As the FEM simulation result, the embossing shape was identified as the better shape for improving the press formability. The selection shape was also performed to produce a better reliability compared to the other shapes.

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