Improvement in Press Formability by Stretch Preforming

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Abstract:

The improvement in press formability of sheet steel is required to achieve sophisticated complex parts design, and compatible high stregth to make lighter weight and comparable crashworthiness for car bodies. JFE Steel has developed a new forming technology, which consists of stretch preforming and substantial main forming, to meet these demands. The key aspect of the technology is the optimization of the preformed shape. In this paper, the effect of the preforming was validated by stretch forming tests with cylindrical punches, and by press trial of a wheel house inner. Furthermore, a spoiler integrated back door outer was press-formed to show that the new technology was suitable for very complicated shape parts.

1. Introduction

In the production of automotive parts, press forming technologies which improve formability are demanded in order to realize well-designed outer panels with complex shape, or body frames with light weight and superior crashworthiness. It is known that dispersing strain is effective for improving drawing and stretch formability[1]. Efficient forming technologies for dispersing strain are incremental forming[2] and hydroforming[3], but takt time is an issue of mass production in these processes. It is possible to satisfy both strain dispersion and takt time by using multiple forming processes. However, it is difficult for multiple forming processes to optimize die face designs of the respective processes. Therefore, this approach through optimization of multiple processes has been limited to simple shapes like square cup deep drawing[4].

JFE Steel Corp. developed a technology for optimizing the die face design of two-step press forming processes which form parts with complex geometries[5]. In the current mass-production of parts, press-forming processes are mainly a two-step process of near-net shape forming and restriking. Thus, the optimization of these two processes makes it possible to improve drawing and stretch formability without increasing the current number of processes.

In this report, the effect of dispersing strain with the two-step process on the stretch formability was verified by forming tests with cylindrical punches[6], and one of the dispersion strains with optimizing the preformed shape was verified by a press trial with the model of a wheel house inner. The effectiveness of the developed technology was also verified by press trial of a full-scale spoiler-integrated back door outer which was hard-to-form by conventional forming technology.

2. Effect of Two–Step Forming Process on Stretch Formability

This chapter shows the effect of two-step forming processes on stretch formability. One-step and two-step forming tests with cylindrical punches were conducted by a finite element method (FEM) analysis.

2.1 Analysis Conditions

The die models used in the forming test are shown in **Fig. 1**. The dimensions of the punch in the one-step stretch forming test (hereinafter, one-step forming) were 150 mm in outer diameter and 5 mm in shoulder

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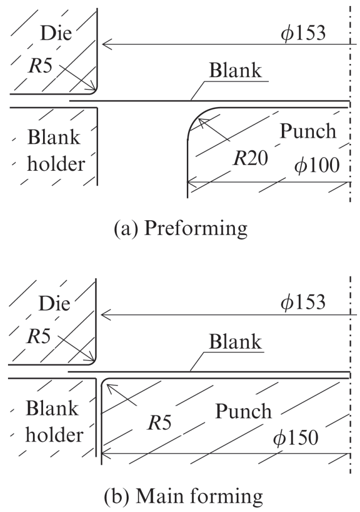


Fig. 1 Tool model of each step for stretch forming test

Table 1 Mechanical properties of steel used in forming test with cylindrical punches

Thickness/mm	YP/MPa	TS/MPa	El/%
0.75	160	290	50

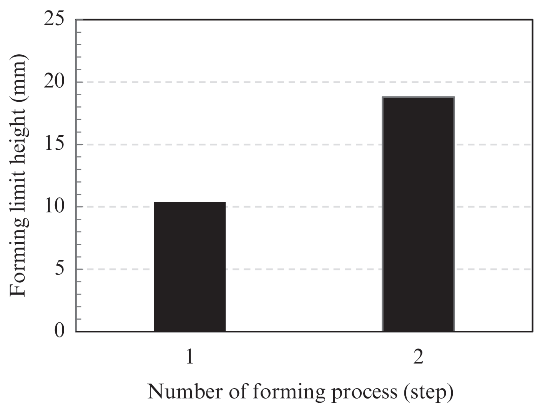


Fig. 2 Dependence of forming limit height on number of forming steps in stretch forming test

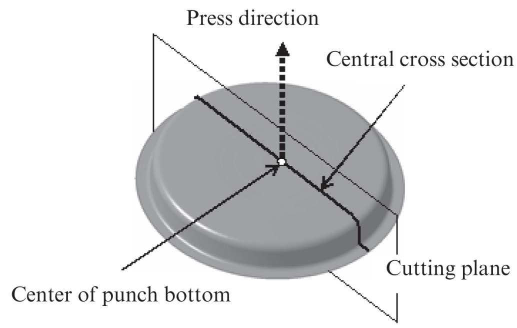


Fig. 3 Central cross section of truncated corn shape along with cross sectional distribution of thickness reduction measured

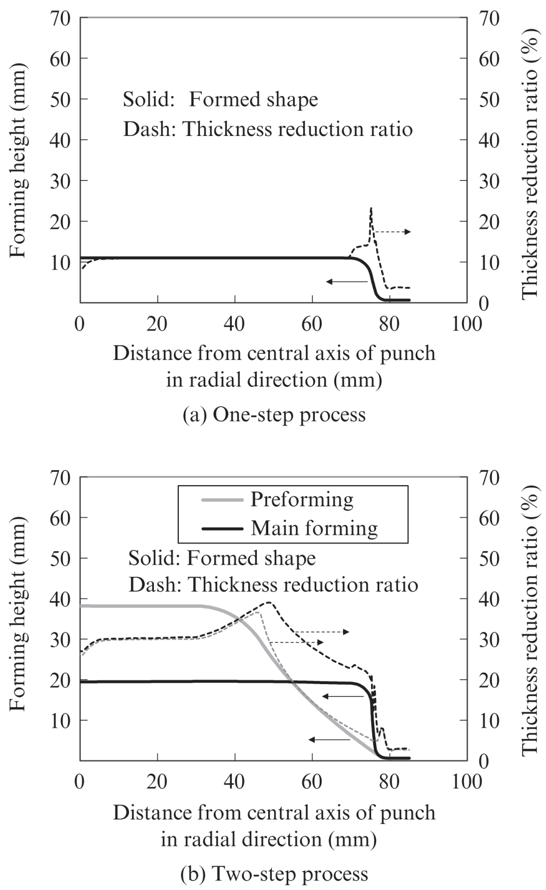


Fig. 4 Relationship between central cross sectional distribution of thickness reduction ratio of formed part and number of forming steps in stretch forming test

radius.

The dimensions of the punch in the first process of the two-step stretch forming process (hereinafter, two-step forming) were 100 mm in outer diameter and 20 mm in shoulder radius. The punch in the second process was 150 mm in outer diameter and 5 mm in shoulder radius. The dimensions of the die were 153 mm in inner diameter and 5 mm in shoulder diameter. The die was common to all forming processes. All tools were modeled as a rigid body.

The blank shape was circular with a diameter of 170 mm. The outer circumference of the blank was constrained in the radial direction.

A 270 MPa grade mild steel with the mechanical properties shown in **Table 1** was used as the blank. An explicit dynamic method code LSDYNA®Ver. 9.7.1 R5 (Livermore Software Technology Corp.) was used for FEM analysis. The friction coefficient between the tools and the blank was set at 0.15, and the fracture in stretch forming was determined by the forming limit diagram.

2.2 Results

The forming limit heights in one-step forming and two-step forming are shown in **Fig. 2**. The forming limit height was 10.4 mm in one-step forming and 18.8 mm in two-step forming. Thus, the forming limit

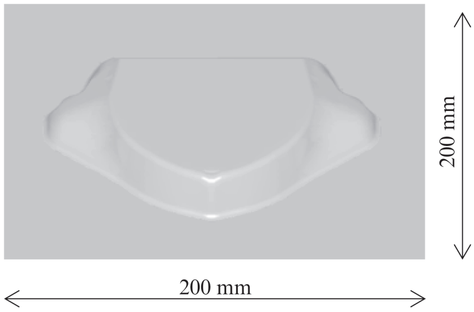


Fig. 5　Target part of wheel house inner

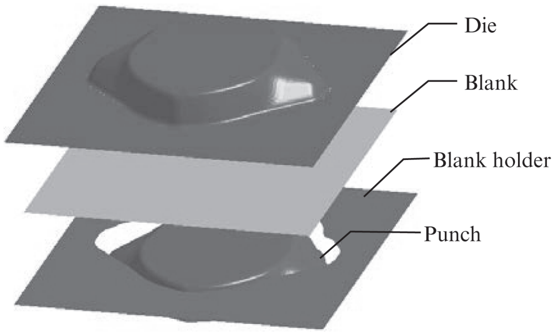


Fig. 6　Initial configuration of blank and tools in main forming to wheel house inner

Fig. 7　Preformed model B (Optimized shape) before main forming of wheel house inner

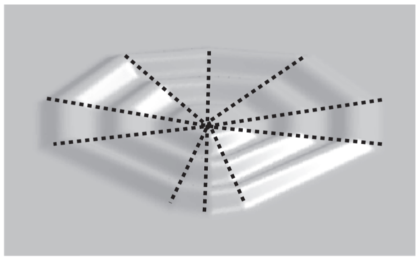
height was improved by 80% in two-step forming.

In order to verify the factors in improvement of stretch forming by two-step forming, the thickness reduction ratios of the formed parts in the respective processes were compared in the central cross section shown in **Fig. 3**. The shape of the parts and the distribution of the thickness reduction ratio at the forming limit height are shown in **Fig. 4**.

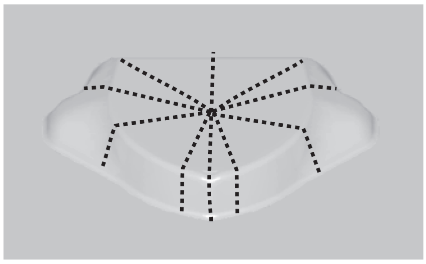
In one-step forming, the thickness reduction ratio increased locally between the shoulder and sidewall of the punch, and the thickness reduction ratio of the web was approximately 11%. In the two-step process, the thickness reduction ratios in each step of the two-step process also increased between the shoulder and sidewall of the punch, but the thickness reduction ratio of the web was more than 22%. High elongation of the web in the two-step process was interpreted as the increase in the material flow from the web to the sidewall because the punch shoulder radius, 20 mm, in the preforming step was large. It was believed that this material flow reduced strain between the radius and sidewall of the punch and improved stretch formability.

Table 2　Mechanical properties of steel used in press trial of wheel house inner

Thickness/mm	YP/MPa	TS/MPa	El/%
0.70	158	299	49



(a) Preforming model B



(b) Part shape

Fig. 8　Optimization of preformed shape for wheel house inner based on cross sectional lengths of part shape

3. Influence of Preforming Shape on Stretch–draw Formability in Two–Step Forming

In this chapter, the developed technology which optimizes the preforming shape was verified by a press trial with a model wheel house inner.

3.1 Experimental Conditions

Figure 5 shows the target model of the wheel house inner.

The press trial was conducted using three different processes. One was a one-step forming process using the stretch-draw forming die shown in **Fig. 6**. The others were two-step processes of a preforming process and a main forming process. The preforming process used two types of model A and B. Model A was a conventional shape using a punch with a spherical head having an outer diameter of 150 mm. Model B as shown in **Fig. 7** was the shape optimized by using the developed technology (hereinafter, design technology for preform die face) discussed in the following section

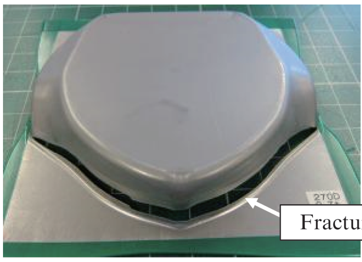
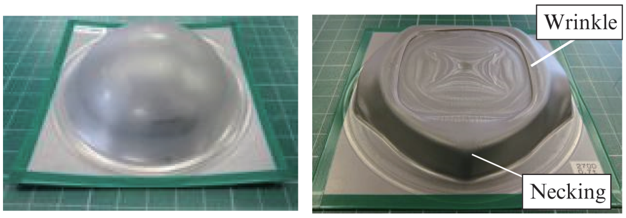
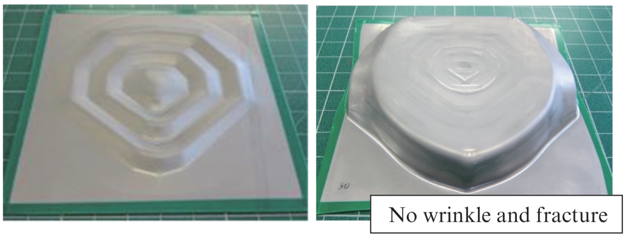


Fig. 9 Fracture in wheel house inner by one-step forming



(a) Preforming with model A (b) Main forming

Fig. 10 Formed shapes by developed simple two-step forming, (a) preformed with Model A, and (b) main formed



(a) Preforming with model B (b) Main forming

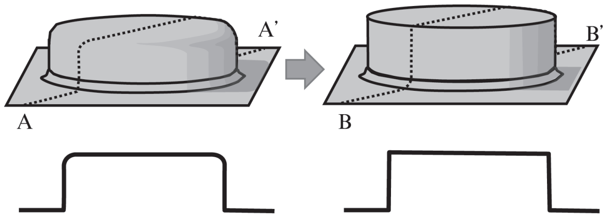
Fig. 11 Formed shapes by optimized two-step forming, (a) preformed with optimized Model B in Fig. 7, and (b) main formed

3.2. The main forming uses the same die as the one-step process. In the preforming process, a blank was formed to 99% of the forming limit height in model A and formed to the bottom dead center in model B.

The blank was rectangular with dimensions of 200 mm × 200 mm, and the tested material was a 270 MPa grade mild steel sheet with the mechanical properties shown in **Table 2**. As the lubrication condition, the blank was formed as-coated with anti-rust oil.

3.2 Design Technology for Preform Die Face

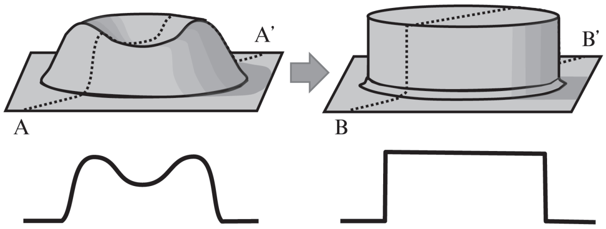
The following describes the design method of preforming model B in Fig. 7. Ten cross sections, as shown in **Fig. 8**, were set for the target part, and the length of each cross section (hereinafter, cross sectional length) was evaluated (Fig. 8b). Then, while keeping the cross sectional length, the radius of the punch shoulder was expanded so as to enable easy press-forming, and the cross sectional shapes were changed smoothly (Fig. 8a).



A-A' section B-B' section

(a) Drawing or stamping (b) Restriking

Fig. 12 Schematic illustration of conventional two-step forming which consists of main forming and restriking



A-A' section B-B' section

(a) Preforming (b) Main forming

Fig. 13 Schematic illustration of developed two-step forming which consists of optimized preforming and main forming

3.3 Results of Press Trial

With the one-step process, a severe fracture occurred at the die shoulder, as shown in **Fig. 9**.

In conventional two-step forming with model A, necking occurred at the punch shoulder and a wrinkle also occurred in the web, as shown in **Fig. 10**. However, fracture didn't occur.

On the other hand, in optimized two-step forming with model B, it was possible to form the part without fracture or wrinkles, as shown in **Fig. 11**.

The conventional press-forming process is a two-step process, as illustrated in **Fig. 12**. The blank is formed to a shape near that of the part (i.e., near-net shape) in the first step. Therefore, the degree of difficulty of forming depends on the part shape. In order to utilize two-step forming more effectively, as shown in **Fig. 13**, it is important to optimize the preforming shape in the first step corresponding to the part shape.

4. Improvement of Part Designability by Design Technology for Preform Die Face

In this chapter, the press trial of a full-scale spoiler-integrated back door outer was conducted, demonstrating the effectiveness of the developed technology.

4.1 Experimental Conditions

The shape of the target part was the spoiler-inte-

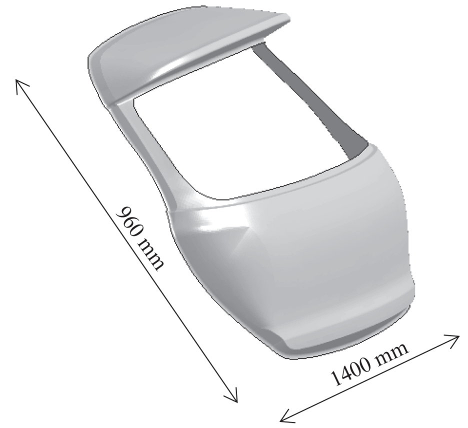


Fig. 14 Target shape of spoiler integrated back door outer

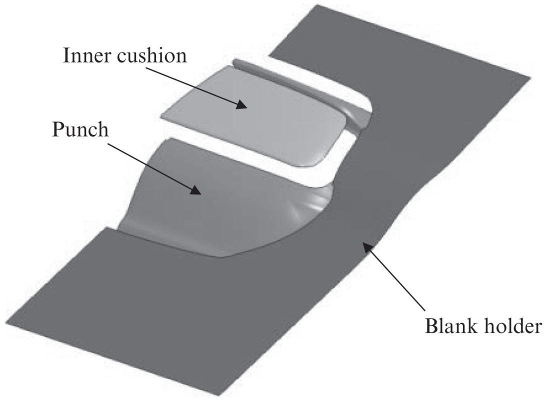


Fig. 17 Initial configuration of lower tools in main forming for spoiler integrated back door outer

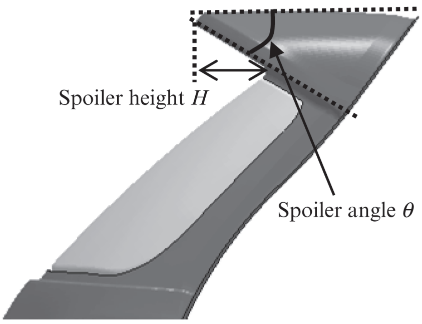


Fig. 15 Definition of spoiler height H and angle θ

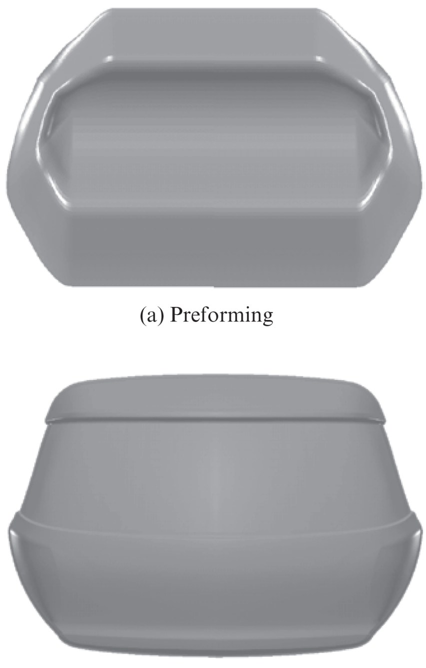


Fig. 18 Optimized preformed shape (a) and main formed shape (b) of spoiler integrated back door outer

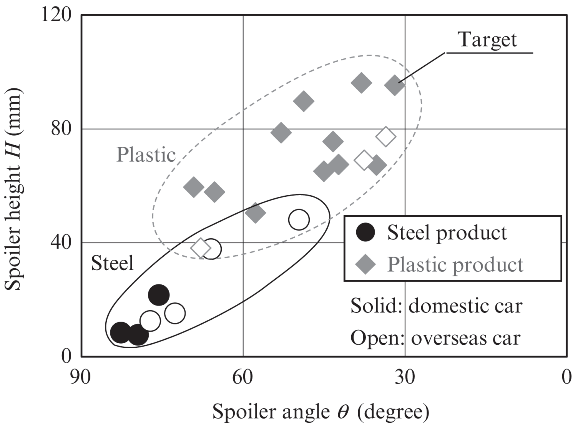


Fig. 16 Spoiler height H and angle θ of target shape compared with those of domestic and overseas cars

Table 3 Mechanical properties of steel used in press trial of spoiler integrated back door outer

Thickness/mm	YP/MPa	TS/MPa	El/%
0.70	155	306	50

grated back door outer shown in **Fig. 14**.

The degree of difficulty of forming the spoiler is expressed by two indexes, the spoiler height H and the spoiler angle θ, as shown in **Fig. 15**. The forming becomes more difficult as θ decreases and/or H increases. Therefore, the target spoiler shape was considered to be a shape with a sharper angle and larger height, i.e., more sophisticated design quality, among commercial automobiles.

Figure 16 shows the relationship between the spoiler height H and angle θ of various commercial automotives. In comparison with steel spoilers, plastic products tend to have a smaller θ and higher H, and thus have a higher design quality. Therefore, the target shape was set at a spoiler height of H = 95 mm and angle θ = 32°, which were the specifications of the plastic spoiler with the smallest θ and highest H among those investigated in this study.

The press trial was carried out under one-step forming and two-step forming. The model of dies shown in **Fig. 17** was used in one-step forming and main forming

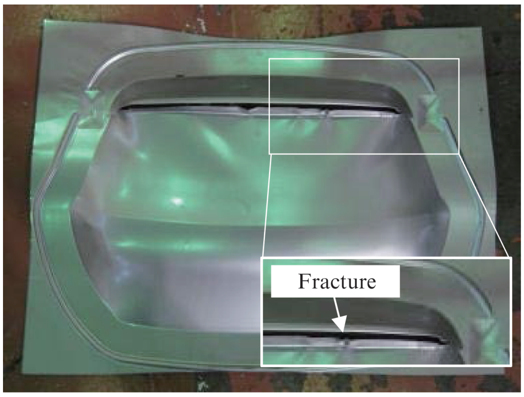


Fig. 19 Fracture in spoiler integrated back door outer by conventional one-step forming

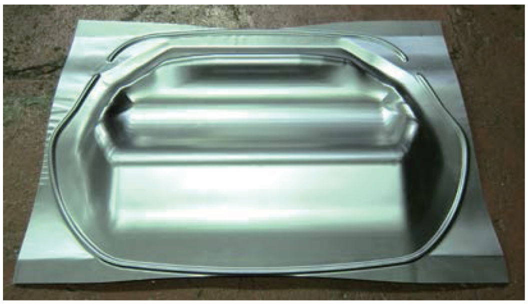


Fig. 20 Preformed spoiler integrated back door outer panel by developed two-step forming

in two-step forming. The structure of the dies contains an inner cushion for pressing the center of the part during draw forming.

Figure 18 shows the formed shape in preforming and main forming by the two-step forming process. The preforming shape was designed using the design technology for the die face described in section 3.2 so as to align all of the cross sectional lengths which were selected in the direction of maximum principal strain in one-step forming.

The blank was a rectangle with dimensions of 1600 mm × 1200 mm. The material used was the 270 MPa grade mild steel with the mechanical properties shown in **Table 3**. As the lubrication condition, the steel sheet was formed as-coated with anti-rust oil.

4.2 Results of Press Trial

In the press trial by one-step forming, a severe fracture occurred at the spoiler, as shown in **Fig. 19**.

In the trial by the two-step process, first, the blank was formed in the preforming process, as shown in **Fig. 20**. Then the central area of the preformed part was cut out for controlling the material flow. Finally, the preformed blank was formed in the main forming process. As a result, the target part shape was formed successfully as shown in **Fig. 21**.

(a) Top view

(b) Side view

Fig. 21 Main formed spoiler integrated back door outer panel by developed two-step forming

The two-step press forming process and the design technology for the preform die face made it possible to form a complex part shape.

5. Conclusion

The design technology for preform die faces was developed for the two-step press forming process. In order to improve stretch-draw formability, optimization of the forming shape in each process is important. This report demonstrated that hard-to-form part shapes with a more sophisticated design quality could be formed by the developed technology. It is believed that the developed technology can also improve the formability of hard-to-form materials, which would be effective in strengthening automotive body parts for the improvement of crashworthiness and weight reduction.

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