Influence of stamping parameters on stamping characteristics of SAF2205 bidirectional stainless steel

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Abstract

SAF2205 bidirectional stainless steel is an excellent material for multiple corrugated diaphragms. It is necessary to study its stamping forming characteristics and provide a theoretical basis for stamping forming of multiple corrugated diaphragms. In this paper, the detailed V-bending process parameters are formulated. The effects of bending speed, relative fillet radius, temperature, and alignment time on spring-back behavior of SAF2205 bidirectional stainless steel are systematically studied to reveal the positive and negative spring-back mechanism. The range of process parameters suitable for stamping of SAF2205 bidirectional stainless steel was obtained.

Article Highlights

- The detailed V-bending process parameters are formulated.
- The effect of SAF2205 parameters on the spring-back behavior was studied.
- The range of process parameters suitable for stamping of SAF2205 was obtained.

Keywords SAF2205 bidirectional stainless steel · Stamping forming · Spring-back · V-bending

1 Introduction

The multiple corrugated diaphragm coupling is a new type of flexible coupling. Its core components are the corrugated diaphragm, which is made of high strength and high toughness stainless steel [1, 2]. High efficiency and high precision forming are critical techniques in fabricating the curved surface of the corrugated film. Considering the material's tensile strength, elongation, and end face shrinkage, SAF2205 bidirectional stainless steel is an excellent stamping material for multiple corrugated diaphragms [3]. Therefore, studying its stamping forming characteristics is necessary to provide a theoretical

basis for the stamping forming of the multiple corrugated diaphragms.

The key to ensuring the forming precision of stamping is to accurately grasp the spring-back law of the materials used in stamping forming. The spring-back of sheet metal stamping is affected by many factors related to the stress state and the strain history [4, 5]. Therefore, to control the spring-back, the spring-back law is often explored by various bending deformation methods, such as V-shaped bending, U-shaped bending, and composite bonding. Among them, V-shaped bending is a relatively simple way of bending. However, V-shaped bending deformation and spring-back behavior are affected by many factors, including fillet radius, temperature, and bending speed. Different

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combinations of deformation parameters can reduce the amount of spring-back after bending to some extent. For example, the rebound can be significantly reduced after bending the plate at a high temperature and conducting subsequent thermal correction [6–8]. At present, V-shaped bending is often chosen to explore the law of the rebound process.

Previous researchers conduct several studies on the spring-back in stamping. Junyan, Xinghuan, Kaiwei et al. studied the effect of different drawing speeds on the profound drawing limit factor of dual-phase steel B340/590DP sheet. Experiment results with the same set show that crack happens quickly when stamping speed exceeds 60 mm/s [9]. Ozdemir, Dilipak, Bostan investigated the effects of bending parameters by creating numerical and mathematical models. Thus, it was determined that spring-go behavior occurred on the IL and NH applied sheet material, while spring-back conduct occurred on the TH used material [10]. Ozdemir, Dilipak, Bostan studied the spring-go and spring-back behavior of 16Mo3 sheet metal due to the V-deep bending process. It was determined that the spring-back value decreased with increasing thicknesses of the sheet metal [11]. Thipprakmas investigated two existing spring-back factors, including the conventional and adjusted spring-back factors. The results showed that, compared with experimental results, the accuracy of the bend angle prediction and the bend radius calculation obtained using the adjusted spring-back factor were better than those obtained using the conventional spring-back element [12]. Chan, Chew, Lee et al. present a spring-back study in the V-bending metal forming process with one clamped end and one free end. Different die punch parameters such as punch radius, punch angle, and die-lip radius are varied to study their effect on spring-back [13]. Tekaslan, Gerger, Seker obtained an amount of spring back in sheet metals at different bending angles by designing a modular "V" bending die. The results have shown that of the four other bending methods used in the field most, two cannot be employed for spring-back effect and that holding the punch longer on the material bent reduces spring back whereas an increase in the thickness of the material, and bending angle increase spring back values [14]. Lal, Choubey, Dwivedi, et al. proposed a relatively complex analysis formula for the spring back problem of stamping parts. By analyzing the parameters that affect the spring-back, the defects like wrinkling, earing, tearing, and spring back is reduced, and also we can get an excellent quality product [15]. Sajan, Amirthalingam, Chakkingal presented a novel V-bending technique for effectively measuring the spring-back. Results indicate that the spring-back decreases and becomes close to zero (at a cooling rate of 20 K S^{-1}), increasing the cooling rate for hot stamping steel [16]. Many scholars have a specific

reference value for the research on spring-back characteristics. However, few studies on SAF2205 bidirectional stainless steel, whose specific stamping parameters still need to be determined by test.

2 Experimental procedure

In this paper, the influence of bending speed, relative fillet radius, temperature, and alignment time on spring-back behavior is systematically studied by formulating detailed technological parameters of V-shaped bending to reveal the positive and negative spring-back mechanism.

Spring-back quantity can generally be expressed as spring-back angle and spring-back radius [17, 18]. The spring-back angle is used to characterize the spring-back amount in this paper. The spring-back angle is the difference between the bending angle after unloading and before unloading (90°). The bending angle is the included angle formed by the two straight arm areas of the bending part. During the bending angle measurement, the three-dimensional coordinate measuring instrument was used to obtain the surface point cloud of the vertical arm region, and the Imageware software was used to simulate the point cloud into the plane. Then the software measurement function was used to obtain the bending angle of the sample. When the spring-back angle is positive, it means positive spring back; when it is negative, it means negative spring back. Rebound degree is defined as the more significant the positive rebound value, the more serious the rebound. The greater the absolute value of the negative rebound angle, the more serious the rebound.

This paper used a 0.8 mm thick SAF2205 high strength steel plate for the bending test. Considering that thickness also influences the spring-back behavior, relative fillet radius (r_p) is adopted to discuss it. The relative fillet radius is the ratio between the fillet radius of punch and sheet metal thickness.

According to the metal material bending test method (GB/T 232-1999), a v-bending test of SAF2205 was carried out on the CMT6305-300kN electronic servo universal testing machine [19, 20]. The punch radii are 1, 2, 4, and 6 mm, respectively, and the V-bend angle is 90 degrees, the bending speeds are 0.02, 0.06, 0.1, 0.5, 1, and 5 mm/s, respectively. The punch is pressed until bent, and the punch is pressed against the bent specimen, as shown in Fig. 1.

After the test, the universal protractor was used to measure the angle of the specimen, Each specimen was measured three times and averaged, and then the spring-back angle was calculated. The universal protractor used in this paper is shown in Fig. 2.

After each bending test, the bending area was scanned by SEM with a size of 51 mm and a height of

Fig. 1 Schematic diagram of 90° V-bending

Fig. 2 universal bevel protractor

8 mm. The SEM used in this paper is SNE-4500 M Plus produced by South Korea Saik Testing Equipment Co., LTD. To control the specimens clean, in the process of SEM using special tweezers to move the samples. In addition, the pieces were ultrasonically cleaned and dried with ethanol before scanning.

Fig. 3 SAF2205 bidirectional stainless steel specimen bent at different bending speeds at a relative fillet radius (r_p) of 5 mm at 750 °C

Fig. 4 Spring back angle-bending speed curve at a relative fillet radius (r_p) of 5 at 750 °C

In addition, to avoid repeating similar images, only SEM photos of specimens with cracks are shown in this paper, and samples without damages are not offered by default.

3 Results and discussions

3.1 Influence of bending speed on spring back

Bending tests were carried out at 750 °C with a relative fillet radius $r_p = 5$ at a bending speed of 0.02–5 mm/s. The samples were quickly unloaded after loading, as shown in Fig. 3. Figure 4 shows the law of spring-back angle

changing with bending speed. It can be seen that with the increase of bending speed, the spring-back angle experienced a change from the maximum negative spring-back angle -3.37° to the maximum positive spring-back angle of 6.09° . According to the analysis, when the bending speed is 1–5 mm/s, due to the high bending speed, the elastic potential energy accumulated in the short time of the sheet is released immediately after unloading, so a large positive spring-back angle is obtained. The faster the bending speed is, the greater the accumulated elastic potential energy is, and the greater the spring-back angle is obtained. When the bending speed is 0.02–0.06 mm/s, the stable load period at low-speed bending is relatively long, 270–90 s respectively, as shown in Fig. 5. Therefore, in addition to the slow plastic deformation, the sheet material also has a certain degree of creep. When the material is stretched at a high temperature, it will creep within a short time after loading, which leads to the reduction of the spring back after the stretching at a high temperature.

In this paper, the creep of the tensile layer and the compression layer after V-shaped bending continues in a relatively short period, and the sample bends inward, leading to a negative spring-back angle. It can be seen that both low and high bending speeds have a significant influence on spring-back behavior. When the bending speed is 0.1–0.5 mm/s, the loading stability period is 6–30 s, and the spring back angle after unloading is close to zero value, so the bending speed has little effect on the spring back. When studying the influence of other parameters on bending and spring back behavior, a relatively moderate bending speed of 0.1 mm/s should be selected.

Fig. 5 Load-bending displacement curve at a relative fillet radius (r_p) of 5 at 750 °C

3.2 Influence of temperature on spring back

Figure 6a and b show the samples and SEM microstructure after punch bending at room temperature and low temperature with the relative fillet radius $r_p = 1.25$ and $r_p = 2.5$. Figure 6c and d show that when $r_p = 1.25$ and 2.5, cracks appear on the outer surface of the sample after bending at room temperature. When $r_p = 2.5$, the sample spring-back angle after bending at 300–400 °C is 11.01° and 10.82° , respectively, showing a high degree of spring-back. When $r_p = 1.25$, the sample's spring-back angle after bending at 550 °C is -3.77° , which is caused by the bending of punch with a small relative fillet radius.

When the relative fillet radius $r_p = 1.25$, the sample after bending at 500 °C presented fine cracks (as shown in Fig. 6), while the sample after bending at 550 °C presented an entire outer surface. For $r_p = 2.5$, cracks appear in the specimen at room temperature, but no cracks appear on the sample's surface after bending at 300–400 °C. The same is valid above 500 degrees Celsius. Thus, it can be determined that when the bending speed is 0.1 mm/s, the limit temperature of bending without fracture of the sample is between 500 and 550 °C when the relative fillet radius $r_p = 1.25$. It can be seen from Fig. 6c and d that the crack growth degree after bending when $r_p = 1.25$ was adopted at room temperature was more significant than that after bending when $r_p = 2.5$ was adopted. At 500 °C, the outer surface crack propagation degree of the sample bending with $r_p = 1.25$ was the lowest because the plasticity of SAF2205 bidirectional stainless steel at 500 °C was better than that at room temperature.

Figures 7 and 8 are samples bent with different relative fillet radius at 600–750 °C and 800–850 °C, respectively. Figure 9 reflects the change rule of spring-back angle with temperature when the relative fillet radius is fixed. It can be seen that when the relative fillet radius $r_p = 1.25$, a negative spring-back angle is obtained in the range of 550–750 °C. The spring-back amount increases gradually with the increase of temperature. When the relative fillet radius r_p is 2.5 or 5, the spring-back angle experiences a transition from positive to negative spring back with the temperature rise. When relative fillet radius $r_p = 7.5$, a positive spring-back angle is obtained in the range of 600–850 °C, and the spring-back angle decreases with the increase of temperature. When the relative fillet radius $r_p = 1.25$, the bending degree is the highest, and the complex stress distribution in the bending deformation zone and the transition zone is the cause of the negative spring back. When $r_p = 7.5$, the bending degree is the lowest. The spring back behavior follows the traditional bending theory: the higher the temperature is, the lower the yield strength ratio to elastic modulus will be, and the lower the spring-back angle will be, when relative fillet

Fig. 6 SEM photograph of the curved outer surface of SAF2205 bidirectional stainless steel specimen and specimen after bending at room temperature and low temperature

Fig. 7 SAF2205 bidirectional stainless steel specimens with different relative fillet radius at 600 °C–750°C

radius $r_p = 2.5$ –5, the effect of temperature on spring back becomes complicated.

Fig. 8 SAF2205 bidirectional stainless steel specimens bent at relative fillet radius $r_p = 5$ and 7.5 at 800 °C–850 °C

3.3 Influence of relative fillet radius on spring back

Figure 10 shows the SAF2205 bidirectional stainless steel samples bent with different relative fillet radius (r_p) at room temperature. It can be seen that, compared with the samples turned by $r_p = 1.25$ and $r_p = 2.5$, there are no cracks on the outer surface of the samples bent by the punch with a relative fillet radius of $r_p = 5$. The bending degree is low when the relative fillet radius $r_p = 4$, enabling the complete loading process before the crack generation. Thus, the minimum relative fillet

Fig. 9 Spring back angle-temperature curve at different relative fillet radius

Fig. 11 Spring back angle-relative fillet radius curve obtained at 600–850 °C

Fig. 10 SAF2205 bidirectional stainless steel specimens bent at relative fillet radius $r_p = 1.25, 2.5$, and 5 at room temperature

radius r_p is between 2.5 and 5 for V-shaped bending of high-strength steel at room temperature.

Figure 11 shows the changing rule of the spring-back angle with the relative fillet radius when bending in the range of 600 – 850 °C. It can be seen that when the temperature is constant, the spring-back angle changes from negative to positive with the increase of relative fillet radius. When a different relative fillet radius is used for bending, the stress distribution in the bending zone and the transition zone are not the same at the end of bending, so the spring back behavior after unloading is also different.

Fig. 12 SAF2205 bidirectional stainless steel specimens with relative fillet radius $r_p = 1.25$ and 7.5 bending and corrected at different alignment times at 700 °C

3.4 Influence of alignment time on spring back

Figure 12 shows the bending sample at 700 °C with the relative fillet radius $r_p = 1.25$ and $r_p = 7.5$, which are adjusted at different times. Figure 13 shows the change curve of the sample's spring-back angle with the alignment time. It can be seen that when the relative fillet radius $r_p = 1.25$, with the increase of alignment time, the spring-back angle is negative, and the spring-back angle gradually approaches zero from -6.69° . When the relative fillet radius $r_p = 7.5$, the sample's spring-back angle after different alignment times is positive. The spring-back angle gradually decreases to zero with the increase of alignment time. Stress relaxation occurs during shape correction. It can be seen from Fig. 12 that the residual stress of each bending layer after the relaxation of 600 s at 700 °C is already

Fig. 13 Spring back angle-alignment time curve with relative fillet radius of 1.25 and 7.5 at 700 °C

minimal, approaching the ultimate relaxation stress. Therefore, after the alignment for 600 s, the spring back values of the bending samples with relative fillet radius $r_p = 1.25$ and $r_p = 7.5$ are -0.03° and 0.05° , respectively, which are very close to zero. According to the changing trend of the spring-back angle with the alignment time, the spring-back angle after the alignment time exceeds 600 s is relative to zero value. Hence, the appropriate alignment time at 700 °C is 600 s.

4 Conclusions

By analyzing the effects of bending speed, temperature, relative fillet radius, and alignment time on the spring-back of SAF2205 bidirectional stainless steel, the following conclusions can be drawn:

- (1) The spring-back angle changes from negative to positive as the bending speed increases. The minimum relative fillet radius that does not break when bent at room temperature is 2.5 and 5. The limit temperature of no fracture when bending with a close fillet radius of 1.25 is 500–550 °C.
- (2) At a temperature range of 600–750 °C and a bending speed of 0.1 mm/s, the spring-back angle changes from negative to positive with the increase of relative fillet radius at a specific temperature. When the relative fillet radius is 1.25 and 5–7.5, the absolute value of the spring-back angle increases and decreases with the rise of temperature, respectively. When the relative fillet radius is 2.5, the spring-back angle changes positively to negative with increasing temperature. Within the range of 800–850 °C, the spring-back

angle varies from negative to positive with increasing temperature, with a relative fillet radius of 5. The spring-back angle with a relative fillet radius of 7.5 is positive. The higher the temperature is, the lower the spring-back angle will be.

- (3) When bending at a specific temperature and relative fillet radius, the sheet transition zone forms an arc near the end stage, and the arc is straightened at the end-stage. The resultant bending moment of the rectified arc and bending zone on the symmetric surface of sheet metal bending determines the rebound amount after unloading. A resultant positive moment causes a positive spring back, and a consequent negative moment causes a negative spring back.
- (4) When the relative fillet radius of 700 °C is 1.25 and 7.5, the spring-back angle gradually approaches zero with the increase of the alignment time from negative spring back and positive spring back respectively, and the optimal alignment time of 700 °C is 600 s.

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Data availability The data used to support the findings of this study are included in the article.

Declarations

Conflict of interest We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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