RESEARCH OF THE WRINKLING ELIMINATION OF STAINLESS STEEL SUS304 BY VISCOUS PRESSURE

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Abstract:

Wrinkling is one of the most important factors influencing a forming precision of sheet metal, which brings difficulties to the forming process of sheet metal. In order to eliminate the wrinkling during the forming process, an accurate prediction is necessary. In this paper, the wrinkling elimination process was investigated based on the principle of the Yoshida Buckling Test (YBT) and viscous pressure forming. The experimental device was designed, and evaluation method of the wrinkling elimination rate was presented by the stainless steel SUS304. On this basis, the wrinkling elimination experiment was carried out, the influences of both the viscous medium molecular weight and the tensile state of wrinkle under the viscous pressure on the wrinkling elimination were obtained.

1 Introduction

With the energy-saving and emission reduction requirements, lightweight technology has been widely used in the fields of aviation, aerospace, and automotive. The application of the sheet structural components has been the main approach to lightweight goal according to its characteristics of light weight and strong loading ability. However, due to the influence of the material properties and geometry of parts, sheet metal is easy to produce defects such as wrinkling or fracturing during the forming process. Therefore, the way to control the forming parameters to avoid wrinkling or fracturing has become the key to improve the forming quality of a sheet with complicated shape [1-4].

Generally, fracture is caused by the tensile instability during forming process, which can be solved through prediction methods such as forming limit diagram, maximum thickness thinning rate criterion, strain rate catastrophe criterion, and appropriate forming parameters or forming methods. Meanwhile, wrinkling is caused by the compression instability, which is influenced by many factors such as forming craft, material property, and stress state. The wrinkling of the sheet metal with complicated shape is difficult to predict accurately during the forming process. Methods for avoiding wrinkling are various depending on different forming processes. A blank holder is employed to prevent wrinkling in the flange area during the drawing process, while for the wrinkling during the tube bending, an adding filler inside the tube can effectively prevent wrinkling [5-8]. If wrinkling is allowed at certain conditions during the forming process, as long as the change of a wrinkle can be controlled to fit the mold before the end of deformation, the size precision can meet the requirements. In recent years, tube-compression by viscous pressure forming aims at controlling the

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variety of wrinkling states and eliminating the wrinkles of tube-blank, forming parts with large deformation accordingly. Therefore, the study on the wrinkling elimination process and the ultimate elimination ability are of great significance for the optimization of the forming process parameters and the improvement of the ultimate deformation ability of sheet metal [9-14].

The YBT (Yoshida Buckling Test) is a method which can use the diagonal tension to evaluate the ability of resisting wrinkling under non-uniform tension This has an important representative of resisting wrinkling in the forming process of the sheet metal. In this paper, based on the principle of the YBT and viscous pressure forming, the wrinkling elimination process and the degree of ultimate elimination were analyzed under different tensile forces and viscous properties. This study can provide a reference for the ability of the wrinkling elimination of sheet metal characterized with complicated shape by viscous pressure forming [15-18].

2   The experimental Scheme and Materials

2.1   The experimental scheme

During the forming process of sheet metal, stress state and location of wrinkles are difficult to control, which brings difficulties to get the wrinkles of same morphology. In order to simplify the research, the morphology similar to the wrinkle is formed through the mold with a die cavity length of 60mm and width of 20mm as shown in Fig.1, and the shape of wrinkle can be controlled by the forming pressure.
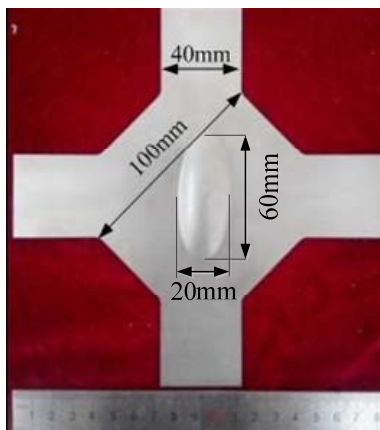

Figure 1. Wrinkling specimen.

2.2   The experimental device

The experimental device was designed (Fig.2), which can eliminate wrinkles by viscous pressure. The biaxial tension was loaded along the X and Y directions on the wrinkling specimen by the drive ball screw controlled by a servo motor. The viscous pressure was loaded along the Z direction by a servo motor.
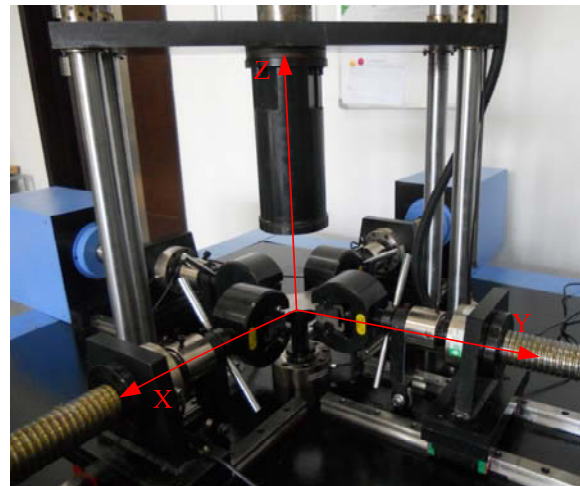

Figure 2. The experimental device.

2.3   The experimental materials

The sheet metal of stainless steel SUS304 with the thickness of 0.7mm was used in the experiment. The tensile test was carried out according to GB/T228.1-2010. In the experiment, the tensile speed is 10mm/min. The experiment was repeated three times as shown in Fig.3. The tensile test data are shown in Table 1. It can be seen that the average load of the specimen, the tensile strength, the yield strength and the elongation are 9.4 kN, 588.3 MPa, 235.1 MPa and at 67%, respectively.

Figure 3. Tensile specimens.

Table 1. Stainless steel SUS304 tensile test data

Sample	Maximum load (kN)	Tensile strength (MPa)	Yield strength (MPa)	Fracture elongation (%)
Sample 1	9.5	597.3	239.3	66.7
Sample 2	9.3	582.3	230.7	68.4
Sample 3	9.3	585.5	235.3	65.9
Average	9.4	588.3	235.1	67.0

Methyl vinyl silicone rubber is used as viscous medium in the experiment. It is the viscous plastic linear polymer which is copolymerized with dimethyl siloxane and little vinyl silicone. The molecular structural formula of the methyl vinyl silicone rubber is illustrated in Fig.4. The main chain is composed of silicon and oxygen atoms The pendant groups connected with silicon are methyl and vinyl. The molecular weights of viscous medium are 40, 50, 60 and 70×10^4 g/mol respectively. The relationships between the shear strain rate and the shear stress of the viscous medium are shown in Fig.5. Moreover, when the molecular weight of the viscous medium is higher, the viscous medium will become more sensitive. The shear viscosity with different molecular weights is shown in Fig.6. The lowest shear viscosity is 12.8 kPa·s when the molecular weights of viscous medium is 40×10^4 g/mol, and the shear viscosity is increased to 25.3 kPa·s when the molecular weights is 70×10^4 g/mol. It can be seen that the shear viscosity increases with the increasing of molecular weight of the viscous medium.
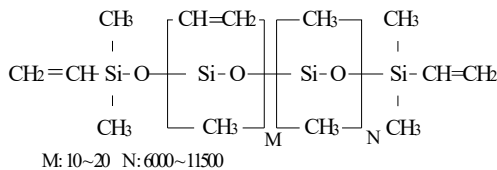

Figure 4. Molecular structure of viscous medium.

3 Analysis of wrinkling elimination

3.1 The stress strain state analysis

The stress and strain state of the wrinkling under viscous pressure is shown in Fig.7. Besides the viscous pressure, wrinkling was also influenced by a tensile or compression stress along length and width directions of the specimen during the

wrinkling elimination process. Considering the force transmission process, only the tensile forces along length and width directions were analyzed. (The tensile force along the length direction is represented by F_L and the tensile force along the width direction is represented by F_W).

3.2 The wrinkling elimination method

In the process of wrinkling, the evaluation method of wrinkle depends on the maximum height of
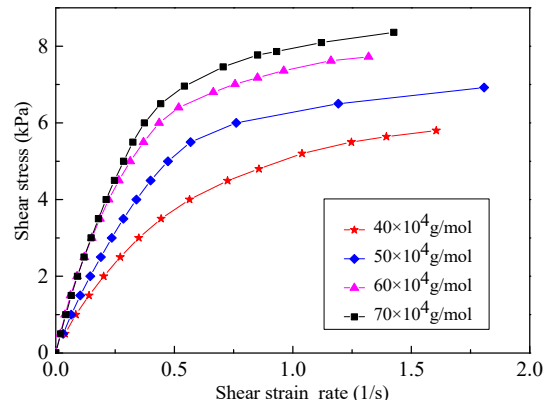

Figure 5. Relationship between shear strain rate and shear stress of the viscous medium.
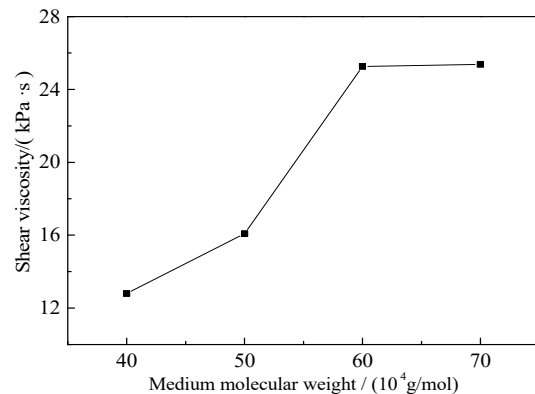

Figure 6. Shear viscosity with different medium molecular weights.

wrinkling H_{max}, the maximum tilt angle θ_{max}, the change of tilt angle $\triangle\theta$ and the minimum curvature radius ρ_{min} as shown in Fig. 8 [19-20]. In the process of wrinkling elimination, some wrinkles can be eliminated completely, but others still have residual height. Considering the macroscopic characteristics and the surface quality factor after the wrinkling elimination, height change of wrinkle is used as the evaluation criteria of wrinkling elimination rate in the process of research.

$$\beta = H / H_{max} \qquad (1)$$

where β is wrinkling elimination rate, H is residual height after wrinkling elimination (mm) and H_{max} the maximum height of wrinkle (mm).
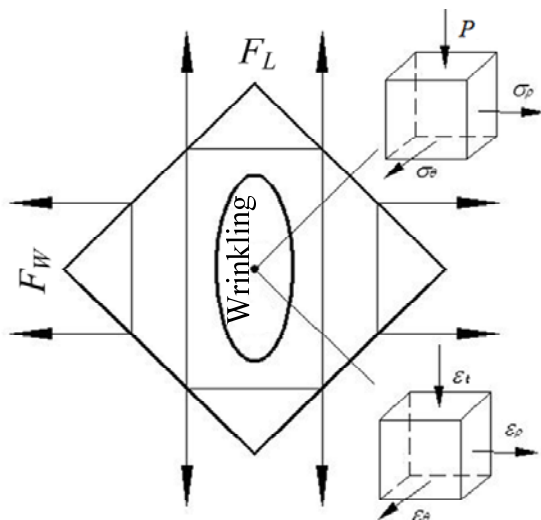

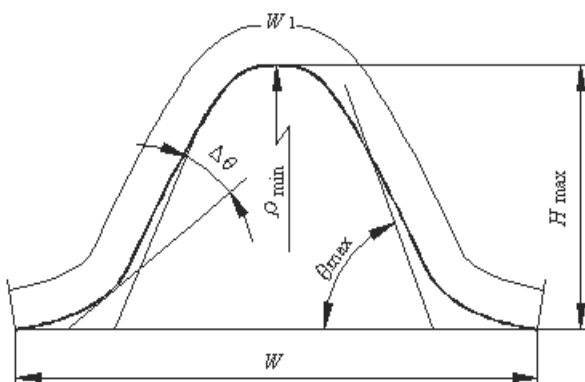*Figure 7. Stress and strain state of the wrinkling by the viscous pressure.*

Figure 8. The evaluation method of wrinkle morphology.

4 The results and discussions

4.1 Influence of the molecular weight of viscous medium on the wrinkling elimination

The results of the wrinkling elimination without tensile force under different molecular weight conditions were measured by height gauge, as shown in Fig. 9. The height of the wrinkle is 4 mm, and the viscous pressure for wrinkling elimination is 30 MPa. The relationship between the molecular weight and the wrinkling elimination rate is shown in Fig.10. The maximum displacement of wrinkling peak is 3.43 mm, and the wrinkling elimination rate is 85.8% at the molecular weight of 40×10^4 g/mol. The maximum displacement of peak of the wrinkle is 3.56 mm, and the wrinkling elimination rate is 89.2% at the molecular weight of 70×10^4 g/mol.
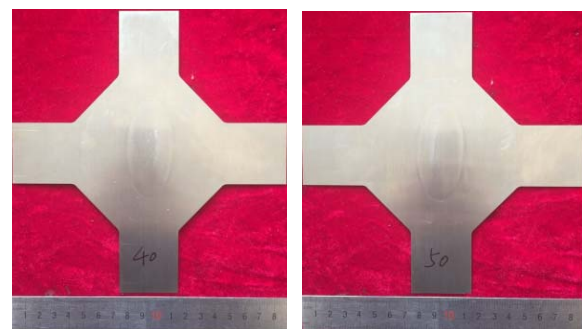
(a) 40×10^4g/mol   *(b) 50×10^4g/mol*
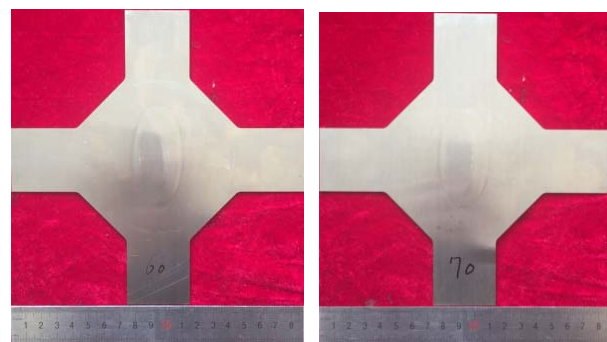
(c) 60×10^4g/mol   *(d) 70×10^4g/mol*

Figure 9. Wrinkling elimination specimens with different molecular weights of viscous medium.

Relatively, the wrinkling elimination rate is increased by 3.4%. It can be seen that the wrinkling elimination rate will be increased when the viscous

medium with larger molecular weight is used. Therefore, the viscous medium with molecular weight of 70×10^4 g/mol will be used in the following experiment.
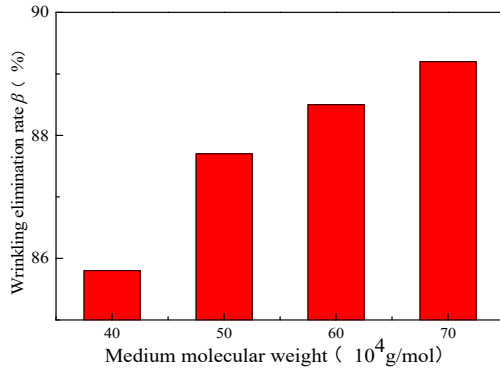

Figure 10. Relationship between the molecular weight of viscous medium and the wrinkling elimination rate.

4.2 Influence of tensile state on the wrinkling elimination

Considering the influence of tensile state on the wrinkling elimination, under the experimental condition, different forces were applied directly along the length and width directions, and viscous pressure was loaded to 30 MPa. The process parameters of the wrinkling elimination under the biaxial tension condition are shown in Table 2.

The specimens of the wrinkling elimination are shown in Fig.11. The wrinkling elimination rate is 96% when F_W=140 N and F_L= 56 N. When F_W=140 N *and* F_L=112 N, the wrinkling elimination rate is 96.6%, which is increased by 0.6%. The wrinkling elimination rate is 94.6% when F_L=140 N and F_W=56 N. When F_L=140 N and F_W=112 N the wrinkling elimination rate is 95.7%, which is increased by 1.1%. The relationships between the wrinkling elimination rate and the variations of tensile forces are shown in Fig.12. It can be seen that the tensile force along the width direction has a more significant influence on the process of the wrinkling elimination. It is because the tensile force is easier to transmit and wrinkling is easier to extend along the width direction, which is helpful in the wrinkling elimination.
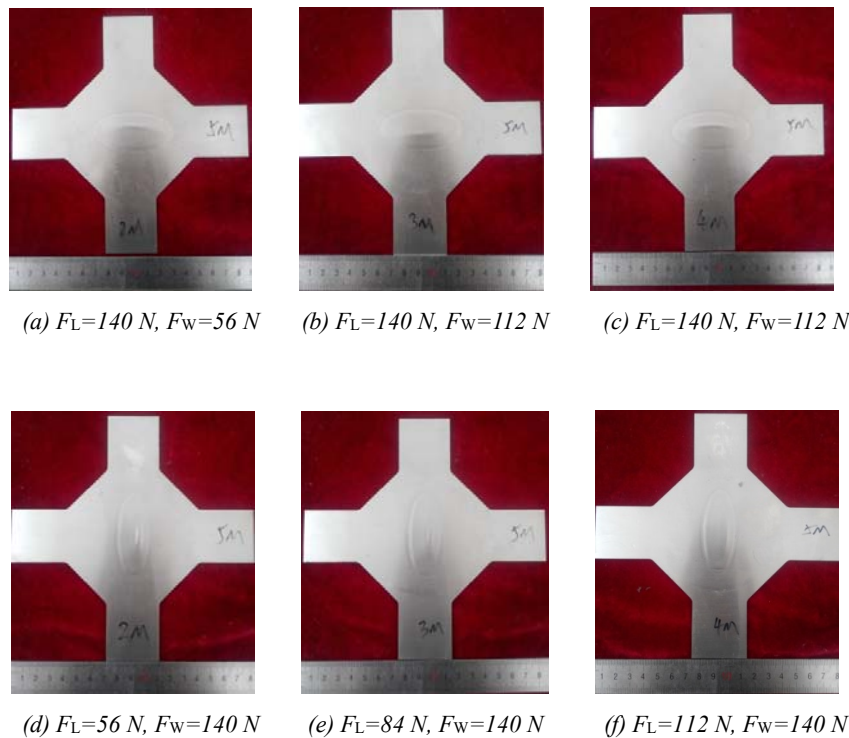

(a) F_L=140 N, F_W=56 N   *(b) F_L=140 N, F_W=112 N*   *(c) F_L=140 N, F_W=112 N*

(d) F_L=56 N, F_W=140 N   *(e) F_L=84 N, F_W=140 N*   *(f) F_L=112 N, F_W=140 N*

Figure 11. The wrinkling elimination specimens with different tensile forces along the length and width directions.

Table 2. The process parameters of the wrinkling elimination under biaxial tension

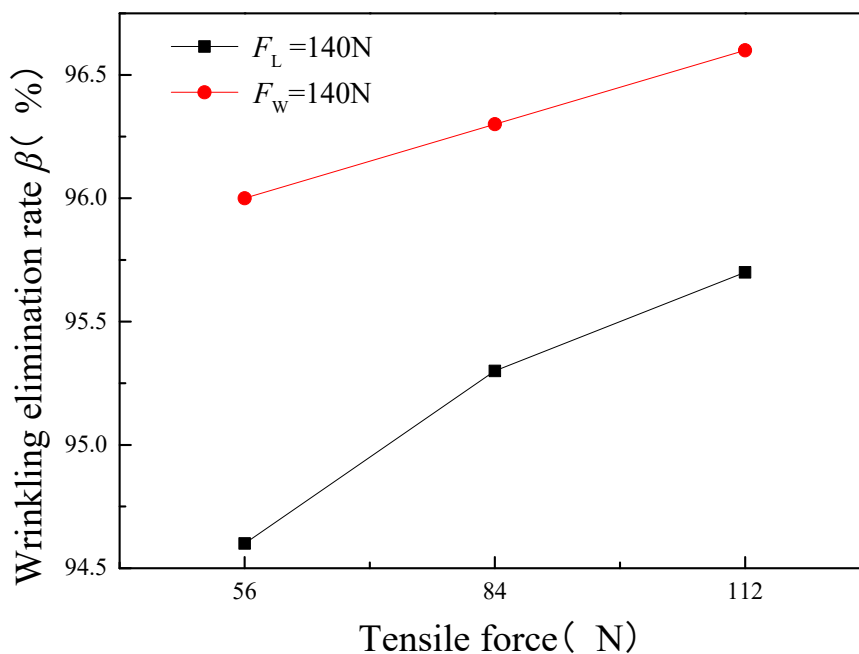| Viscous pressure P/ (MPa)	Tensile force along the length direction of wrinkle F_L / (N)	Tensile force along the width direction of wrinkle F_W / (N)	The wrinkling elimination rate β/ (%)
30	140	56	94.6
30	140	84	95.3
30	140	112	95.7
30	56	140	96.0
30	84	140	96.3
30	112	140	96.6

Figure 12. The relationships between the wrinkling elimination rate and tensile state of wrinkle.

5   Conclusion

Aiming at the problem of wrinkling of sheet metal, a certain geometrical wrinkle was formed according to the principle of the YBT, and the wrinkling elimination under the condition of viscous pressure was investigated. The results can be extracted as follows:

(1) At the same condition of viscous pressure, when the molecular weight is larger, the viscous medium becomes more sensitive, and higher wrinkling elimination rate can be obtained.

(2) At the same condition of viscous pressure, the tensile state of wrinkle plays a great influence on the wrinkling elimination rate. When the tensile force becomes greater, the wrinkling elimination rate is higher.

(3) Compared with the length direction of the wrinkle, the tensile force exerted at the width direction is beneficial to the transmission of tension, which has a more significant influence on the wrinkling elimination.

Acknowledgments

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