INFLUENCE OF WELD JOINT QUALITY ON STABILITY OF SUS304 TUBE-COMPRESSION BY VISCOUS PRESSURE FORMING

Tiejun Gao [1*] – Hepeng Zhang[1] – Yuyin Yang[2] – Zhongjin Wang[3]

[1] Faculty of Aerospace Engineering, Shenyang Aerospace University, No. 37 Daoyi South Avenue, Shenyang 110136 Liaoning, China
[2] Beijing Power Machinery Research Institute, Beijing 100074, China
[3] School of Materials Science and Engineering, Harbin Institute of Technology, 92 West Dazhi Street, Harbin 150001 Heilongjiang, China

ARTICLE INFO

***Article history*:**
Received: 09.06.15.
Received in revised form: 01.10.15.
Accepted: 08.10.15.

Keywords:
Tube-compression
Stability
Viscous pressure forming
Weld joint quality

Abstract:

One of the major problems affecting viscous pressure forming (VPF) is the stability of tube-compression, whereas the main defect influencing the stability of welded tube-compression is the quality of welded joints. This article utilizes the finite element method to analyze the influence of weld joint strength and width on stability of SUS304 tube-compression by VPF. Meanwhile, SUS304 welded tube-blanks with different weld joint strength and width are obtained by plasma welding, TIG-Tungsten Inert Gas welding, laser welding and high frequency welding and then the stability test by VPF is carried out. The results showed that the weld joint strength and width affect the stability of tube-compression. The system and process of controlling weld joint width can improve the stability of tube-blank preferably relative to weld joint strength.

1 Introduction

Tube compression of thin walled parts is affected by its stability, which can easily lead to buckling; it is not easy to control the forming process and the forming quality is difficult to guarantee [1-3]. Viscous pressure forming (VPF) method has been developed in recent years. This method can not only postpone the buckling of tube-blank, but also eliminate wrinkles on the surface of the tube-blank under non-uniform and high viscous pressure. In this way, the influence of buckling and wrinkling to the viscous pressure forming is postponed under certain conditions. Thereby, the large deformation of tube-blank can be obtained [4-6].

The thin-walled tube parts formed by VPF, postponing of tube-blank buckling, and the elimination of wrinkles belong to key technologies. In addition to the performance of viscous medium and the loading method, the buckling is affected greatly by tube-blank quality. As the size and specification of seamless tube is limited, most of tube-blank is processed by roll bending and welding, so the stability of tube-compression is directly affected by the quality of weld joint [7-10]. At present, the existing research is mainly

[*] Corresponding author. Tel.: +8613504999851
E-mail address:tiejun_gao@163.com

concentrated on the stability of tube-blank in uniformly distributed load or axial compression load, research on the stability of the welded tube-blank, however, has not yet been mentioned by VPF. In this article, the influence of weld joint strength and width on stability of SUS304 tube-compression by VPF is analyzed by finite element and is verified by experiment [11-16].

2 Experimental scheme and device

The experimental device (as shown in Fig. 1) is mainly composed of a piston, inner die and outer die. The wall thickness of SUS304 tube-blank t is 1.2 mm, it is welded by plasma welding. Parameters of plasma welding process parameters are: welding current is 40 A, welding speed is 35 cm/min, the plasma gas flow rate is 1.8 l/min, the distance of the nozzle to the workpiece is 5 mm, tungsten setback is 1 mm, whereas the ones of TIG-Tungsten Inert Gas welding are: welding current is 65 A, welding voltage is 7.5 V, welding speed is 35 cm/min,laser welding is characterized by: laser power of 50 W, pulse width of 5 ms, the amount of defocusing of 3 m, welding speed was 30 cm/min; high frequency welding is characterized by: welding frequency of 380 KHz, welding speed of 50 m/min, and the power of 200 kW. The diameter D = Φ64 mm and the height h = 120 mm, the Chemical composition of SUS304 is shown in Table 1. The material of viscous medium adopts methyl vinyl silicone rubber with molecular weight of 70×104 g/mol and viscosity of 25,340 Pa·s. After the welded tube-blank had been put into die, enough viscous medium was filled and placed for 3 to 5 hours so that the bubble was expelled and the influence of mixed with air to the test result could have been avoided. During the test, the pressure loaded outside of the tube-blank through the viscous medium compressed by piston. The speed of piston was 5 mm/s. The test temperature was controlled at 20 ℃ (± 2 ℃). The test data was recorded and saved by the computer.

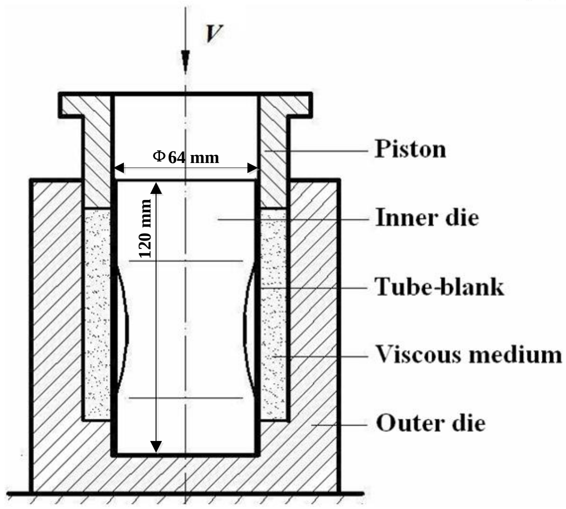


Figure 1. Experimental device.

In order to obtain weld joint quality of different welding methods, tensile tests were processed. Two pieces of SUS304 sheet were welded together and then cut into standard specimens. The size of tensile specimen is shown in Fig. 2. Tensile speed was 5 mm/min. Each test was repeated three times. The fracture generally occurred in HAZ, part occurred in weld metal. The specimens after the tests are shown in Fig. 3. The averages of the tensile data are shown in Table 2. Compared with the base metal strength, the weld joint strengths of plasma welding, TIG welding, laser welding and high frequency welding are 98.9 %, 93.6 %, 87.4 % and 83.8 %, respectively The welding performance of plasma welding was the best, TIG welding followed by the effect of high frequency welding and laser welding is relatively poor (as shown in Fig. 4).

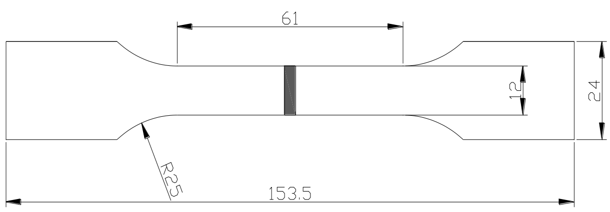


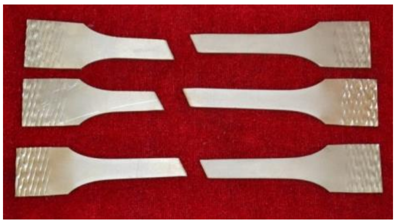
Figure 2. Size of tensile specimen.

Table 1. Chemical composition of SUS304 (wt. %)

C	Cr	Mn	Ni	Si	P	S
0.07	18	2	9	1	0.03	0.03

(a) High frequency welding *(b) Laser welding*

(c) TIG welding *(d) Plasma welding*



(e) No welding

Figure 3. Tensile specimens.

Table 2. Tensile properties of welded samples and base metal

	Maximum load (kN)	Tensile strength (MPa)	Yield strength (MPa)	Uniform elongation (%)
High frequency welding	8.8	453.3	187.9	11.9
Laser welding	9.2	472.9	196.9	34.0
TIG welding	10.1	506.4	214.0	46.8
Plasma welding	10.4	535.0	220.8	51.6
SUS304	10.5	540.9	223.6	53.9

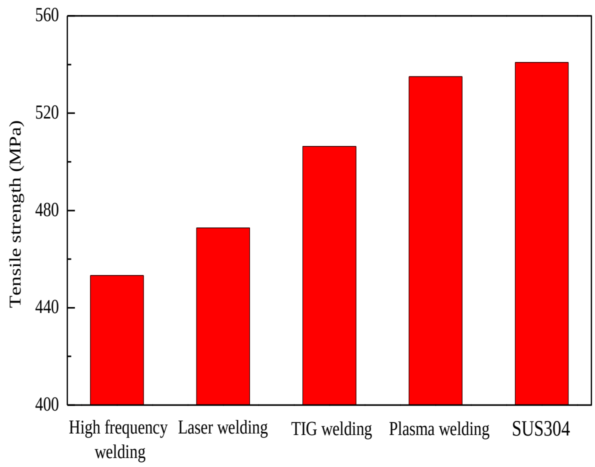


Figure 4. The comparison of weld tensile strength under various welding processes.

3 Finite element analysis

3.1 Finite element model

According to the coupling deformation between viscous medium and tube-blank, the stability of welded tube-compression achieved by VPF is analyzed by finite element software ANSYS/LS-DYNA. A quarter of the finite element model in addition to inner die is shown in Fig. 5. Viscous medium utilizes 3D - Solid for meshing, welded tube, whilst other parts utilize Thin-Shell for meshing, the meshing of weld joint needs refining, the piston y direction is not imposed constraints, the friction coefficient between tube-blank and viscous medium is 0.2. Weld joint strength levels are 100 %, 90 %, 80 % and 70 % of the base metal and the weld joint widths are 2 mm, 4 mm, 6 mm and 8 mm. The weld joint width includes weld metal and HAZ.

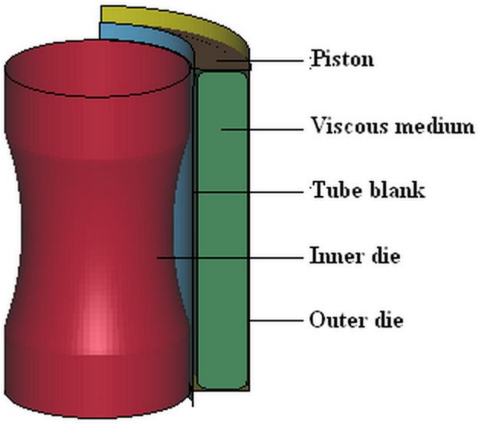
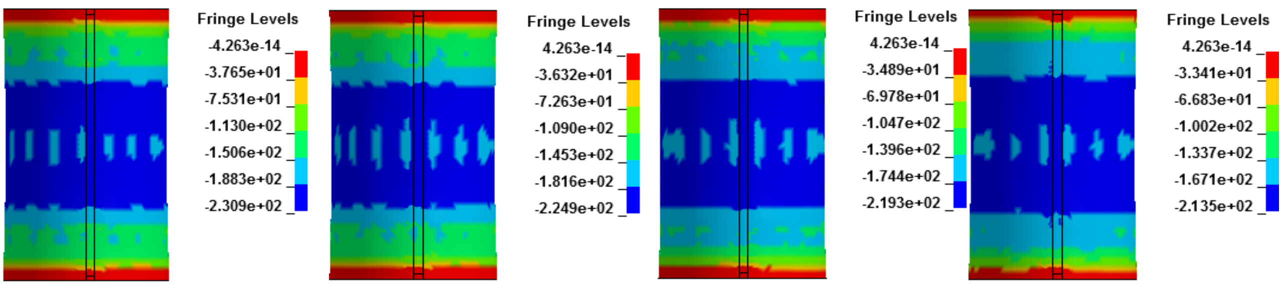


Figure 5. Finite element analysis model.

3.2 Results of finite element analysis

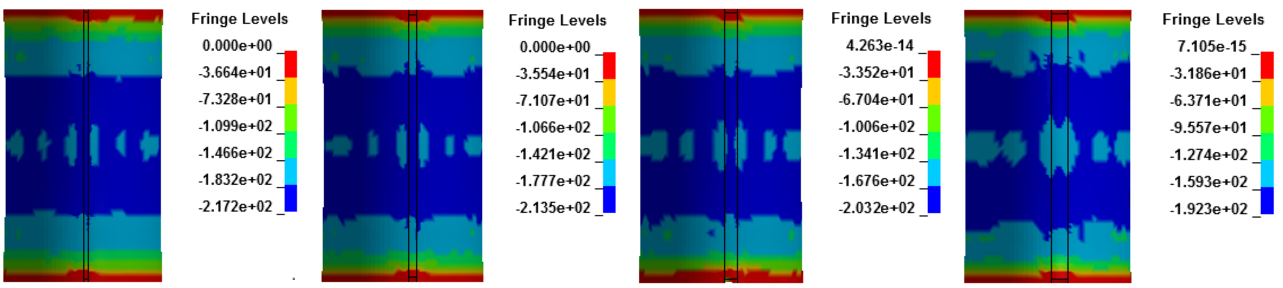
The compression stress produces significant fluctuation causing the tube not to continue keeping its initial equilibrium called buckling. Therefore, the buckling is related to the size and distribution of tube compression stress. Fig. 6 shows the distribution of tube buckling compression stress under different weld joint strength conditions when weld joint width is 4 mm. Compared with the base metal strength, the buckling compression stresses of different weld joint strengths are -230.9 MPa, -224.9 MPa, -219.3 MPa and -213.5 MPa. The lower the weld joint strength, the smaller the tube buckling compression stress is. The stress is decreased to 92.4 % when the weld joint strength is 70 %.

Fig. 7 shows the distribution of tube buckling compression stress under different weld joint width conditions when the weld joint strength is 70 % of the base metal strength. The weld joint width is 2 mm, 4 mm, 6 mm, 8 mm and the corresponding buckling compression stresses are -217.2 MPa, -213.5 MPa, -203.2 MPa and -192.3 MPa, respectively. The larger the weld joint width, the poorer the stability of tube-blank is. The stress is decreased to 88.5 % when the weld joint width is 8 mm.



(a) 100 % *(b) 90 %* *(c) 80 %* *(d) 70 %*

Figure 6. The buckling compression stress of different weld joint strengths.



(a) W=2 mm *(b) W=4 mm* *(c) W=6 mm* *(d) W=8 mm*

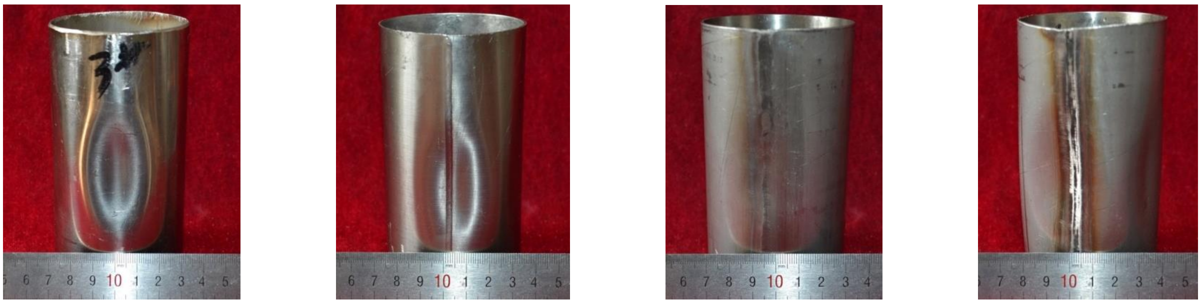
Figure 7. The buckling compression stress of different weld joint widths.

4 The experiment results and analysis

In this article it is shown how the buckling of welded tube-compression is carried out. Viscous pressure drops are rapidly accompanied by clear noise. Fig. 8 displays the buckling specimens of welded tube by VPF, whereas the comparison of weld joint quality and buckling pressure is shown in Table 3. The corresponding relation between the buckling pressure of tube-compression and the bucking stress is shown in Equation 1.

$$\sigma_\theta = -K\frac{pD}{2t}, \tag{1}$$

where, σ_θ is compression stress (MPa), K is correction coefficient (K=0.4), p is buckling pressure (MPa), D is the diameter (mm), t is the thickness (mm).



(a) High frequency welding *(b) Laser welding* *(c) TIG welding* *(d) Plasma welding*

Figure 8. Tube-compression specimens.

Table 3. Buckling pressure of different weld joint widths

Welding process	Laser welding	TIG welding	High frequency welding	Plasma welding
Weld joint width (mm)	2	4	6	8
Strength ratio (%)	87.4	93.6	83.8	98.9
Buckling pressure (MPa)	21.5	21.2	20.3	19.6

Fig. 9 shows the contrast of tube-blank compression stresses calculated by Equation 1 and the results of finite element analysis. The comparison presented in Table 3 and Fig. 8 shows that the buckling pressure made by laser welding tube is the highest, and it is followed by TIG welding tube and high frequency welding tube; buckling made by the plasma welding tube is the lowest. However, the weld joint width of the laser welding tube is the smallest with an average of 2 mm, the width of TIG welding and high frequency welding is in the middle, whereas the width of plasma welding is the biggest with an average width of 8 mm. Thus weld joint width is the main factor influencing the stability. When the weld joint strength of tube-blank (stress-strain are shown in Fig. 10) is lower, the welding zone will be the first to enter the deformation stage, and work hardening phenomenon occurs with an increase in pressure. Then it can lead to an increase in weld joint strength and gradually in the strength of the base metal. Meanwhile, the unfavorable factors of low weld joint strength are offset. Therefore, in the buckling stage, the influence of the weld joint width on buckling is relatively obvious. A reasonable welding process for reducing the weld joint width can avoid prematurely buckling of welded tube employed by VPF.

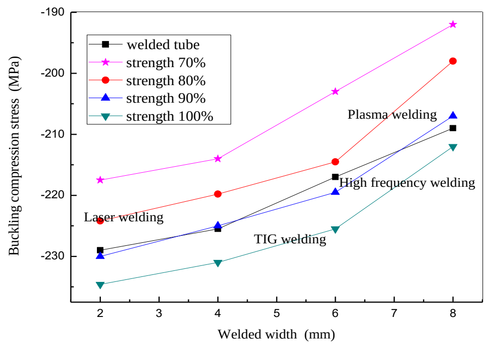
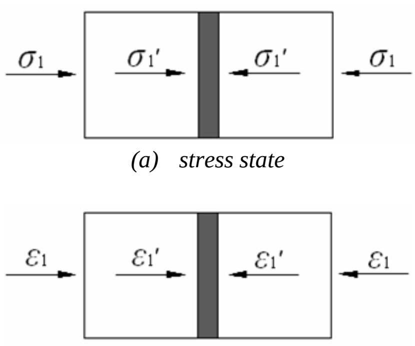


Figure 9. Relationship between weld joint width and buckling compression stress.



(a) stress state

(b) strain state

Figure 10. Stress-strain of weld and base metal.

5 Conclusions

1. The weld joint quality of thin-walled parts, including strength and width, formed by VPF, affects the stability of welded tube-blank.
2. In the process of numerical analysis, the buckling compression stress of tube-blank is inversely proportional to the weld joint width, and directly proportional to the weld joint strength, whereas the buckling is always distributed over the weld joint.
3. The results of comparisons of the influence of weld joint strength and width on the stability of welded tube-blank show that the influence of weld joint width is a little larger, and the influence of weld joint strength is relatively small due to compression deformation and work hardening.
4. When tube-compression by VPF is processed by welding, plasma welding showed the best weld joint characteristics for application; the welding process, however, has to improve the stability of tube-blank which is chosen to reduce the weld joint width under strong enough weld joint condition.

Acknowledgments

The work was supported and helped by the National Natural Science Foundation of China (51205260) and the Program for Liaoning Excellent Talents in University (LJQ2015083). Both of them are greatly acknowledged.

References

[1] Siegert, K., Lopez, P.: *Hydroforming at tube with external high pressure*, 1st Inernational Conference on Hydroforming, Stuttgart, 1999, 463-480.

[2] Siegert, K.: *Research in hydroforming at the instituer of metal forming technology of the University of Stuttgare*, 3st Inernational Conference on Hydroforming, Stuttgart, 2003, 245-258.

[3] Pešić, I., Turkalj, G.: *Finite element bucking analysis of grillage structures*, Engineering Review, 27 (2007), 1, 39-47.

[4] Wang, Z. J., Gao, T. J.: *Inner and outer pressure forming of the nickel based super-alloy thin-walled part with variable diameter sections*, Transactions of Nonferrous Metals Society of China, 18 (2008), 2, 87-92.

[5] Gao, T. J., Liu, Z. J., Wang, Z. J.: *Research on forming process and deformation rule for the Necking of viscous medium under outer pressures*, Advanced Materials Research, 482-484 (2012), 2126-2130.

[6] Gao, T. J., Liu, Y., Wang, Z. J.: *Research on process window diagrams of tube-compression by viscous pressure forming*, Journal of Materials Engineering and Performance, 23 (2014), 6, 2020-2024.

[7] Chu, G. N., Wang, X. S., Liu, G. et. al.: *Weld movement of tailor-welded tube hydroforming*, Materials Science & Technology, 16 (2008), 1, 25-30.

[8] Lu, J., Sun, B., Tang, F., et. al.: *Numerical simulation of temperature field of plasma arc remelting on EN-SGJ-600-3*, Engineering Review, 33 (2013), 1-3, 115-121.

[9] Jou, M.: *Real time monitoring weld quality of resistance spot welding for the fabrication of sheet metal assemblies*, Journal of Materials Processing Technology, 132 (2003), 102-113.

[10] Shyu, S. W., Huang, H. Y., Tseng, K. H. et. al.: *Study of the performance of stainless steel A-TIG welds*, Journal of Materials Engineering and Performance, 17 (2008), 2, 193-201.

[11] Deng, D., Murakawa, H.: *Numerical simulation of temperature field and residual stress in multi-pass welds in stainless steel pipe and comparison with experimental measurements*, Computational Materials Science, 37 (2006), 3, 269-277.

[12] Beltrão, M. A. N., Bastian, F. L.: *Fractographic analysis of weld metal and HAZ regions of API X-80 steel subjected to*

simulation of the Reel-Lay method, Journal of Materials Engineering and Performance, 23 (2014), 10, 3523-3533.

[13] Chen, X., Yu, Z., Hou, B. et. al.: *Prediction model for forming limit of welded tube hydroforming*, Journal of Materials Processing Technology, 47 (2011), 20, 116-126.

[14] Min, D. K., Kim, D. W.: *A finite-element analysis of the electromagnetic tube-compression process*, Journal of Materials Processing Technology, 38 (1993), 93, 29-40.

[15] Palumbo, G., Tricarico, L.: *Effect of forming and calibration operations on the final shape of large diameter welded tubes*, Journal of Materials Processing Technology, 164 (2005), 20, 1089-1098.

[16] Nakamura, T., Hiraoka, K., Zenitani, S.: *Improvement of MIG welding stability in pure Ar shielding gas using small amount of oxygen and coaxial hybrid solid wire*, Science and Technology of Welding & Joining, 13 (2008), 1, 25-32.