Study on Welding Process of 7×0.5 Multilayer 304 Bellows and Flange

Zhaodong Jiang, Dong Liang, Tong Zhou and Linlin Tong
Shenyang Chenguang Futai Bellows Co., Ltd., Shenyang, China

Abstract. In order to ensure the welding quality of 7 layers of 0.5-thk 304L bellows and flange, the welding process was studied, and the evolution rules of weld zone forming, mechanical properties and microstructure under four different process conditions are analyzed to determine the best welding process. The results show that the four kinds of welding conditions can obtain the welded joint with good appearance, but the macro fracture analysis shows that for the welding of 7x0.5 bellows, 2mm double-layer welding is the best welding method. At this time, the distance between the outer wall of the bellows and the inner wall of the flange is the smallest, and the penetration is the largest; For the combination welding method of seam welding and fusion welding, the hardness of the seam welding area is the highest, followed by that of the fusion welding area, because the seam welding area is mainly small equiaxed distance, while the fusion welding is mainly coarse columnar crystal.

Keywords. Corrugated pipe, welding technology, 304 stainless steel.

1. Introduction
The bellows expansion joint is composed of one or more bellows and its structural components. It is mainly used to absorb the displacement and deformation of equipment or pipes caused by thermal expansion and contraction. Bellows are widely used in many forms, with bellows as the core. Bellows compensators are mainly divided into metal bellows compensators and non-metal bellows compensators. Among them, metal bellows are divided into static compensation and dynamic compensation bellows compensator [1]. The bellows expansion joint is different from the general pressure parts or pipe parts of the factory or pipeline, because it can bear the pressure of the pipeline system or equipment, but also meet the strength requirements. It is suitable for large-scale equipment, pipeline and high-rise buildings, absorb underground sediment, compensate displacement and deformation, and meet the structure and safety; Absorb the pipeline vibration caused by vibration source, absorb vibration and isolate vibration, and seal the structure to ensure safe operation. Because bellows expansion joint has the above functions, bellows have been widely used in energy, petrochemical industry, electric power, metallurgy, transportation, municipal administration, building water supply and drainage, gas, heating and heating, wire and cable wiring, agricultural water-saving irrigation and industrial sewage, mine mineral transportation and other fields, playing an important role in national economic construction and people's life [2].

Wang Zhansheng et al. [3] analyzed the process of welded bellows joint, and effectively improved the weld quality of welded bellows by controlling the parameters such as end exposure, weld width, weld crater height, etc. Graduate Cheng et al. [4] used macroscopic observation, energy spectrum analysis, metallographic examination, microhardness test and other methods to study the cracking of stainless steel bellows, which showed that the main cracking form of bellows was fatigue cracking.
Qin Jian [5] and others summed up the application of bellows, and divided bellows into chemical industry, oil refining industry, aerospace industry, medical equipment, shipbuilding industry [6].

Through the summary of the above literature, the welding of 304 stainless steel bellows has been involved, but the number of layers of bellows is generally small (less than 5 layers), and the 7 × 0.5 bellows has not been studied. Therefore, this paper studies the welding process of 7 × 0.5 304 bellows, analyzes the laws and optimizes the process by testing and analyzing the mechanical properties and microstructure of the welded joints under different process conditions, so as to determine the welding process of 7 × 0.5 bellows and guide the subsequent production and manufacturing.

2. Test Materials and Methods
The flange material used in the test is 304 stainless steel, the specification is ϕ 880 × 55 mm, the material used for bellows is 304L, the structural form is 7 × 0.5 mm. In order to ensure the integrity of the multi-layer bellows and facilitate the subsequent welding with the flange, the 7 × 0.5 mm bellows first adopts resistance seam welding technology to weld the ends together, and then uses GTAW to weld the bellows and the flange. The joint form of fusion welding is shown in figure 1. The welding material is er308l, the diameter of welding wire is ϕ 2.5 mm, the polarity of power supply is DC positive connection, and the welding process parameters are: The welding current is (180-230) A, the welding voltage is (10-15) V, the welding speed is (20-30) cm/min, and the air flow is (15-20) L/min. The welding process test mainly adjusts the assembly clearance and the number of welding layers, specifically. There are four process states: single-layer welding without gap, double-layer welding without gap, single-layer welding with 2mm gap and double-layer welding with 2mm gap. The test pieces are successively marked as 1, 2, 3, 4 according to the test sequence. After welding, the welding joints are sampled and analyzed. The specific inspection contents include the macro, mechanical properties and microstructure of the weld. The differences of the structures and properties under different process conditions are analyzed to determine the best process.

![Figure 1. Test plate groove structure.](image)

3. Experimental Results and Analysis

3.1. Macroscopic Appearance and Defects of Joints
Figure 2 macroscopic appearance of welded joint under different process conditions. It can be seen from figure 2 that the fusion effect of the fusion welded joint is very good in all process states. There is only one small pore in 2 mm single layer state, and no obvious micro defects are found in other states. For seam welding, there are very obvious cavities in the condition of no gap and double layer. The cavities are located in the central area of the weld nugget of seam welding, and the size is large, about 1mm is close to the thickness of two layers. Therefore, it is speculated that the cavities should be formed by the unclean materials cleaned before welding, in the subsequent high-pressure and high current welding process, if the subsequent surface treatment is strengthened, it should be avoided.

In order to more clearly analyze the influence of each process state in figure 2 on the forming and quality of welded joints, the corresponding data in figure 2 is summarized and figure 3 is drawn. Three sets of data are included in figure 3, including the distance between the bellows and the base plate, the penetration of fusion welding and the width of fusion. For the distance between the bellows and the base plate, the distance between the double-layer welding and the single-layer welding is less than that between the two-layer welding, and the distance between the two-layer welding and the final welding is the smallest. This phenomenon occurs because under the condition of the gap, it is easy to observe
during the assembly process, and it can realize the manual fine adjustment of the gap. Compared with the physical figure in figure 2, it can be found that the penetration of 2 mm single-layer welding is indeed very large, which has reached the thickness of the bellows, but the joint with the flange is not fully penetrated, and there is a certain gap, which indicates that most of the heat in the welding process is absorbed by the bellows, resulting in poor fusion welding with the flange end face. For the weld width, the rule is basically the same as the distance between the bellows and the base plate. The reason for this phenomenon is the same as the weld depth.

![Figure 2](image-url)  # Microscope morphology of welded joint under different process: (a), (c) no gap, single pass welding; (b), (d) 2 mm gap, multi-pass welding.

![Figure 3](image-url)  # Welding joint forming parameters under different process conditions.

3.2. Hardness Testing

As the joint form of this product belongs to construction joint, it is impossible to prepare tensile specimen for tensile performance test, so hardness test shall be carried out for the seam welding area, the surface and section of the fusion welding area and the base metal area of the welded joint, and the results are shown in figure 4. From figure 4a, it can be seen that the hardness of the seam welding surface is the highest, the hardness of the base metal is the lowest, and the fusion welding surface is in the middle, which is related to the characteristics of the welding process. Seam welding itself belongs to solid-state welding, and the welding process is completed under the double action of power on and pressure. The formation of weld area bears certain upsetting force, that is to say, the solidification of weld metal is completed under the action of external force, and then the weld has a strengthening effect; In the process of fusion welding, the weld metal is melted into liquid state by heat source and then solidified into a whole. The whole heating and solidification time are relatively short, and the growth time of weld metal grain is relatively short, which has a certain refining effect on the fusion welding structure. In addition, compared with the three groups of curves, it can be found that the hardness error of the surface hardness of the fusion welding area fluctuates in the largest range and the seam welding is smaller, which indicates that the mechanical properties of each part of the fusion welding are not very uniform due to the crystal nucleation of the fusion welding. In order to further compare the change laws of the mechanical properties of the surface and section of the two welding methods, the data are summarized as shown in figure 4b. From figure 4b, it can be found that for seam welding, the hardness of the weld surface is higher than that of the weld interior, while for
fusion welding, the hardness of the weld surface is higher than that of the section except for gapless double-layer welding. It can be seen from the above that, in general, the hardness of the weld surface is higher than that of the section. The hardness is higher than that of the section, because the weld surface is in direct contact with the air, the heat dissipation condition is good, the cooling speed is fast, and it is easy to form a small equal wheelbase, thus improving the mechanical properties.

3.3. Metallographic Examination

The evolution rule of the mechanical properties of the weld was preliminarily determined by the hardness analysis, but the deep reason was not known. Therefore, the microstructure of the welded joint was observed. Due to the same welding process specifications and theoretically the same microstructure evolution rule of the seam welding area, the microstructure of the weld area is only analyzed for the 2 mm double-layer welding, and the results are shown in figure 5. From figure 5, it can be seen that the microstructure of the weld nugget area is uniform and fine equiaxed grains, and the fusion line can be clearly observed in the heat effect picture, and there is no obvious micro defect in the fusion line accessories, which indicates that the interlayer fusion of the bellows is good; in addition, the grain size of the base metal on the upper side of the heat effect picture is significantly larger than that of the fusion line accessories and the weld nugget area. This is the basic reason why the hardness of weld zone is higher than that of base metal. This situation is mainly related to the process characteristics of seam welding. The material to be welded is heated to the melting state under high current, and then formed under the action of upset force. The whole process takes a very short time and the cooling speed is fast, resulting in the instant nucleation and rapid growth of austenite, forming a fine equiaxed crystal structure in the center of the weld; and the rolling action of the ring electrode will take place Recrystallization and grain crushing further refine the structure [7], and ultimately improve the mechanical properties of the seam welding area.

However, according to the process characteristics of this product, the main function of seam welding is to facilitate the subsequent assembly, and the main bearing joint of the whole joint is the fusion welding joint. Therefore, it is necessary to conduct in-depth study on the fusion welding joint, analyze its microstructure evolution, so as to explain the root cause of its mechanical property change. It can be seen from figure 5 that the structure of the base metal is equiaxed and the microstructure is dense; the fusion line is clear. Except for a large number of black precipitates in the fusion line area of single-layer welding without gap, the fusion line area is very “clean” under other process conditions, without a large number of precipitates or micro defects. The microstructure of the weld side of the fusion line is perpendicular to the growth of the fusion line, with obvious directionality, mainly columnar crystal. This is because the temperature of the base metal is low, which makes the fusion line area have a great temperature gradient, and then promote the formation and growth of columnar crystal.
Figure 5. Microstructure of melting welding heat affected zone: (a), (c) no gap, single pass welding; (b), (d) 2 mm gap, multi-pass welding.

Figure 6 shows the microstructure of the weld zone. It can be seen from figure 6 that the microstructure of the weld area under the four process conditions is mainly columnar crystal, but there are some differences between them. For two kinds of process conditions without gap, the weld area is obviously columnar crystal, but the distance between primary dendrites of columnar crystal in single-layer welding is significantly larger than that in double-layer welding, which shows that the superheat degree of single-layer welding is higher than that in double-layer welding. In the case of 2 mm gap, the columnar crystal has changed to dendrite, and the directionality of the columnar crystal in the weld is obviously reduced, and the dendrite appears. This phenomenon shows that the original large temperature gradient of double-layer welding is broken, which destroys the production conditions of columnar crystal, which is beneficial to improve the tensile and comprehensive mechanical properties of welded joints.

Figure 6. Microstructure of melting welding zone: (a), (c) no gap, single pass welding; (b), (d) 2 mm gap, multi-pass welding.

4. Conclusion

(1) Four kinds of welding conditions can obtain the welded joint with good appearance, but the macroscopical fracture analysis shows that for the welding of 7 × 0.5 bellows, 2 mm double-layer welding is the best process, at this time, the distance between the bellows and the bottom plate is the smallest, and the penetration is the largest.

(2) for the combination welding method of seam welding and fusion welding, the hardness of the seam welding area is the highest, and the hardness of the fusion welding area is the lowest, because the seam welding area is located in a small equiaxed position, while the fusion welding is mainly based on a large columnar crystal.

Reference

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