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Transient Welding Distortion of the Thick-wall Pipes Circumferentially Welded by All-position Narrow Gap TIG Welding

Jianxun ZHANG*, Jing NIU*, Zhenzhen XU*, Weidong ZHANG**
***State Key Laboratory for mechanical behavior of materials, Xian Jiaotong University, Xian, 710049, China**
****China Nuclear Industry 23 Construction Co. Ltd. Yanjiao Economic & Technical Development Zone, 101601, Beijing, China**

ABSTRACT: In the paper, the thick-wall pipes of 304L stainless steel used in nuclear power station are circumferentially welded with an all-position narrow gap TIG welding machine and the transient welding distortions were automatically measured. Conclusions show that the axial welding distortion is strongly related with the filling of the weld groove and heat input, and the axial welding distortion occurs mainly in the two-thirds filler depth of the weld groove from the inner surface, while the axial distortion barely exists in the rest of the weld groove. As the heat input is critical to axial shrinkage, the axial shrinkage could be controlled by continuous welding with less heat input.

KEY WORDS: Welding Distortion, Thick-wall Pipes, All-position Narrow Gap TIG Welding

1. Introduction

The welding distortion is one of the main factors affecting the dimensional stability and service life of the welded structures. To ensure the quality of welded structure and improve the machining accuracy, it is necessary to dig into welding distortion, especially the formation and causation of the welding distortion.

L.Karlsson et al. in Sweden analyzed welding residual stress and distortion of thin-wall pipes welded by plate splicing in 1980's [1]. Significant researches were performed in the prediction and control of welding residual stress and distortion by K. Masbuchi et al. of MIT in America [2]. J. A.Penso analyzed the bending distortion of mild steel sheet, and suggested an engineering way of inherent strain to predict welding residual distortion in 1992[3]. Professor Ueda Yukio et al. in Japan predicted welding residual stress and distortion with inherent strain [4]. Wang Rui of Xian Jiaotong University, conducted researches on transient angular distortion of 5A12 Al alloy by argon arc welding, trying to describe the transient angular distortion with the characteristic values [5].

Deng Dean and Murakawa H [6-7] of Osaka University in Japan, studied butt-welded mid-thickness Austenitic stainless steel pipes. The thickness of the pipe was 23mm. And the pipe was welded by TIG welding with 14 passes. I. Sattari-Far and Y. Javadi[8] of Amirkabir University in Iran, studied the effect of welding sequence on the distortion of pipes, and suggested a sequence to reduce welding distortion effectively. The pipes used were butt-welded pipes with diameter of 274 mm, and thickness of 62 mm. Erika Hedblom[9] of Lulea University of Technology in Sweden, compared the distribution of residual stresses which welded by two kinds of mid-thickness pipes and three kinds of weld grooves. Xu Jijin [10] of Shanghai Jiaotong University studied butt-welded pipes with thicknesses of 52 mm and 42 mm separately. And he analyzed the effect of vibratory on the residual distortion in multi-layer and multi-pass welding.

Above achievements concentrate mainly on sheets or thin or middle wall pipes, and a few researches are conducted on welding distortion of thick-wall pipes. The reasons may be as the follows: the structure of thick-wall pipes is so complex that the welding position is not fixed; the welding is multi-layer and multi-pass, and the cost of welding is expensive; the amount of data is large and the process of data acquisition is difficult. However, the study of the welding stress and distortion of thick-wall pipes is important while thick-wall pipes are widely used in engineering applications such as nuclear power stations, oil and gas industries, etc.

There are few reports founded about transient welding distortions of thick-wall pipes welded circumferentially by all-position narrow gap TIG welding. This paper includes data acquisition of transient welding distortion and the analysis of the process of transient distortion during welding. The research is significant to improve the reliability of the welded structure of thick-wall pipes, which plays a crucial role in both theories and engineering applications.

2. Experimental Procedure

The experiment pipes are 304L stainless steel ones with diameter of 680mm, and wall thickness of 70mm. The pipes are fixed in a horizontal position and butt welded automatically by all-position TIG welding with narrow groove.

The experiment apparatus consists of welding equipments and measuring instruments. The welding equipment is an all-position TIG welding system with automatic wire filling. And the measuring instruments including displacement sensor and data acquisition card. The distortions are measured with LanHua Inductive Frequency-Modulation Displacement Sensor. And the data is collected by YanHua Data Acquisition Card.

We concern mainly on axial distortions and the swing of the axis of weld during welding. Because of the expansion and contraction of the weld and the heat affected area of thick-wall pipes, the amount of axial distortion of the whole pipe is large enough to make it possible to use displacement sensors to measure macroscopic deformation far from the weld area.

The data is collected by computer automatically, and the process of the transient distortion of thick-wall pipes is monitored thoroughly. There are 4 sets of displacement sensors. The process of data transmission is shielded against electrical interference. Fig. 1 shows the arrangement diagram of displacement sensors in welding.

Although the quality of all-position narrow gap TIG welding is good, it is inefficiency. The welding is intermittent, which lasts about 12 days. The experiment is only carried out during working time.

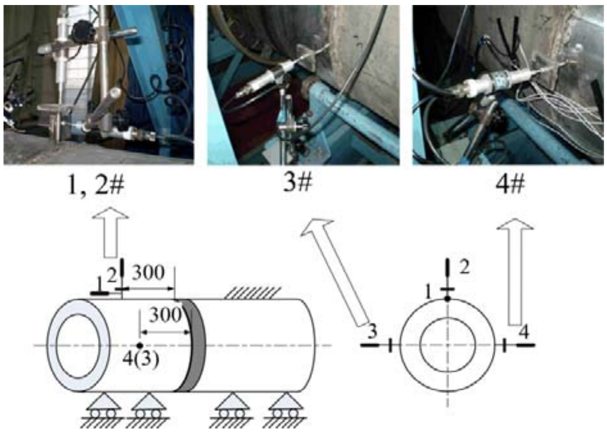


Fig.1 The arrangement diagram of displacement sensors

3. Transient Welding Distortions of Pipes

3.1 Time domain analysis of axial welding distortions

The pipes are butt welded by all-position narrow gap TIG welding with 73 passes. In the former 20 passes, the welding process is stable and successive. While the number of runs increases, the values of welding parameter increase at the same time, which begins from backing weld. Between the 20^{th} pass and the 60^{th} pass, higher values of welding parameter are adapted to satisfy the requirement of wider groove and higher efficiency, which causes the rise of the temperature of the pipes gradually. Moreover, the welding process is unstable at the overhead position of welding. After the 60^{th} pass, it is the stage of filling up. In this stage, the values of welding parameter decrease slightly. And the welding process is stable again. It is repair welding during which the pipes are welded by a half circle mostly. The last pass is cosmetic welding.

We consider the shrinkage during each noon and each night as a contractive stage. As for the filling up stage, the number of several half runs is taken as one contractive stage. In total, the number of contractive stages is 95, as shown in Fig.2. The negative shrinkage means expansion.

Fig. 2 illustrates that the shrinkage is always large in the one third filler depth of the weld groove near the inner surface. And the shrinkage ranges between 0.1~0.4mm. The shrinkage of the rest of the weld groove is mostly negative, which means that the pipes are expanding rather than contractive. Among the expanding runs, there are few contractive runs. But the shrinkage is less than 0.1mm. So the contractive runs have no effect on the tendency of the distortions of the whole pipes, considering of the interference of welding arc.

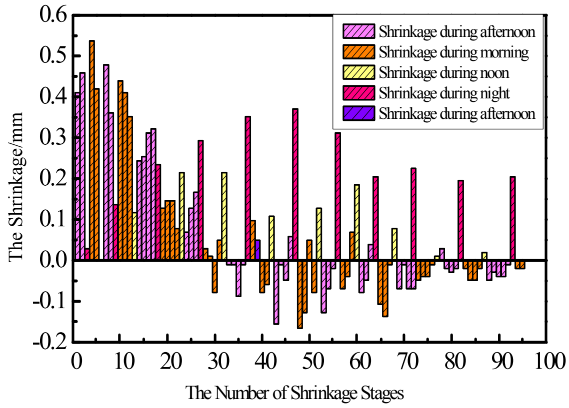


Fig.2 Axial shrinkage during the whole welding process

Fig.2 also shows that the cooling time is 1~2 h at noon, which is much shorter than it at night. So the shrinkage at noon is smaller than it at night. At noon, the shrinkage is large in the two thirds filler depth of the weld groove near the inner surface, while the shrinkage of last several runs is small. At night, the shrinkage keeps increasing until it reaches the peak. After the 60^{th} passes, it maintains stable at a relatively high value.

In the former 20 passes, the weld metal contracts so freely that the amount of axial distortion becomes large. It is caused by the low rigidity of pipes and the little expansion. As for the intermediate 20 passes, the rigidity of pipes increases. Therefore, axial distortion appears as contraction deformation and expanding with heat and contracting with cold. As for the last dozens of passes, distortion appears mainly as expanding with heat and contracting with cold because of the high rigidity and little contraction.

Axial shrinkage concentrates mainly on the former 20 passes. The distortion of the intermediate 20 passes appears mainly as expanding with heat and contracting with cold instead of axial distortion. After the 40^{th} pass, the axial shrinkage is almost zero because the contraction with cold during un-working time is offset by the expansion with heat during working time.

3.2 Analysis on transient axial distortions

Above is the analysis of the shrinkage of each run separately. To dig into the transient distortions during the whole welding process, the curve of transient distorting (Fig.3) is useful. The welding time is 1800s, the cooling time is 1200s, and the total of a run is 3000s. And the total time of the experiment is 240000s if the rest time is wiped out, while the actual time of the experiment is 12 days with rest. Fig.3 illustrates that distortions (axial shrinkage) concentrates mainly on the former 20 passes, which is 95% of the total shrinkage, while the distortion of the remaining passes (about over 40 passes) is 5%. In the former 20 passes, the curve rises though there is trip point at night. After 20 passes, as the initial temperature is room temperature, there is large shrinkage caused by the cooling at night. During welding, the shrinkage decreases because the pipes expand with heat. It could be seen from the slope of the actual curve in Fig.3 that the shrinkage increases sharply in the former 20 passes as the curve is steep. While in the next 20 passes, the shrinkage increases slowly as the slope of the curve has slowed down. And in the rest of the passes, the shrinkage is stable as the curve is flat.

There is large axial shrinkage during un-working time.

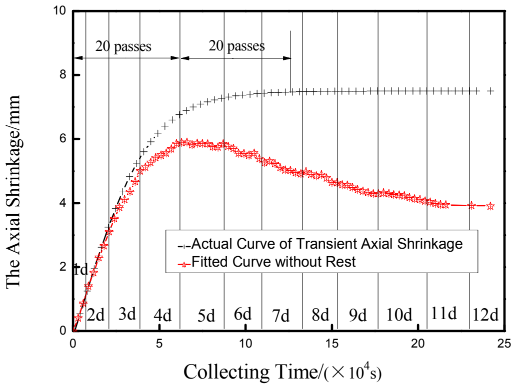


Fig.3 Curves of transient axial distortions

Assuming that the pipes are welded by continuous welding, and interpass temperature is appropriate, the shrinkage will form the curve with blue blocks. In the former 10 passes, the fitted curve is close to the actual curve of transient axial distortion. The process of contraction is quick that it finishes soon after the welding is finished, which means that long time cooling has no effect on axial distortion. The reasons are the small thickness of filler metal, the small rigidity of pipes and the high cooling rate. After 10 passes, the two curves are not close because of the shrinkage caused by long time cooling. If the welding is continuous, the curves will reach its peak at about the 20^{th} pass, which is much lower than the peak of the actual curve. As the contraction becomes more and more difficult caused by the increase of the rigidity of pipes with the successive filling of the weld metal, the temperature of pipes will keep rising or maintain a high temperature if the welding is continuous, which will cause the fall of the curve of the axial shrinkage and the expanding of the pipes.

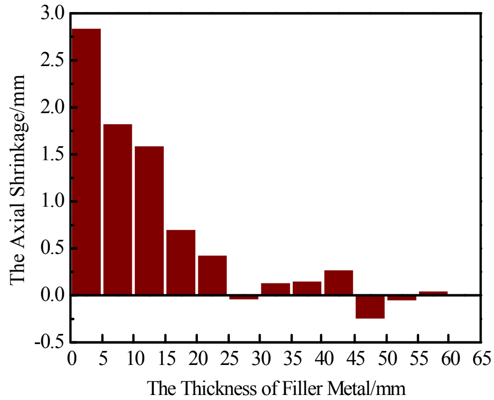
In conclusion, the maximum of the axial shrinkage will decrease by 20% if it is continuous welding. If interpass temperature is controlled, the axial shrinkage will be small because the pipe will expand when heated during welding, which equals pre-stretching.

3.3 Effect of filler metal thickness on axial shrinkage

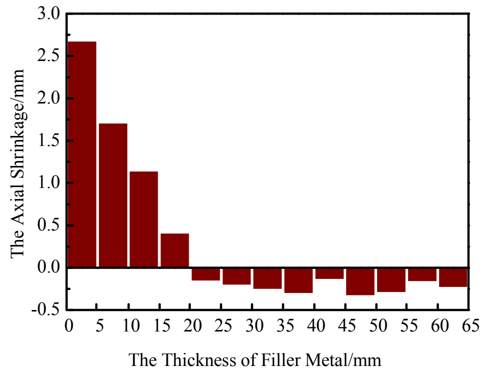
Above is the analysis of welding process which relies on the numbers of runs. It is only one of the situations in welding, and the number of runs of each pipe is different. The thickness of filler metal is crucial to axial shrinkage as it affects the rigidity of pipes. So it is meaningful to analyze axial shrinkage from the thickness of filler metal.

It is related between the thickness of filler metal and axial shrinkage. The weld groove of the pipes is similar with the single V groove. The practical thickness that needs to be welded is 65 mm. The weld groove is divided by 5 mm from the root, as shown in Fig.4. Fig.4(a) shows the shrinkage of pipes welded by intermittent welding, while Fig.4(b) shows the shrinkage of pipes welded by continuous welding.

Fig.4(a) shows that the shrinkage tends to decrease. The axial distortion in the former 25 mm of the filling of the weld groove is the main contractive part. In 25~50 mm, the shrinkage is not over 0.03 mm each 5 mm. After 50 mm, there is little axial distortion. The shrinkage in Fig.4(b) is smaller than it in Fig.4(a) as the shrinkage during un-working time is removed. And the main contractive part is in the former 20 mm. After 20 mm, it appears mainly as expanding with heat, which is helpful to reduce shrinkage.



(a) Intermittent welding



(b) Continuous welding

Fig.4 The axial shrinkage of pipes

If the shrinkage of different filler depth of the weld groove is accumulated, the tendency of the shrinkage will be presented in the curves below, as shown in Fig.5.

During intermittent welding, there is no weld metal at the beginning and the rigidity of the pipes is small in the former 20 mm of the filling of the weld groove. Therefore, the first two runs penetrate easily. Moreover, contraction deformation is common and the amount of shrinkage is large. In 20~40 mm, contraction becomes more and more difficult with the filling of the weld metal and the rising of the rigidity, which means that the shrinkage reduces with the increasing of the number of runs. After 40 mm, the rigidity is so large that there is little shrinkage.

During continuous welding, continuous welding shows no difference with intermittent welding in the former 10mm

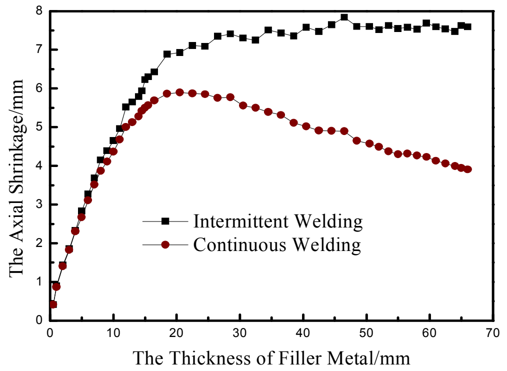


Fig.5 Transient distortions with the thickness of filler metal

of the filling of the weld groove. After 10mm, the shrinkage of continuous welding is smaller than it of intermittent welding. The slopes of the two curves both decrease. At the 20 mm, the shrinkage reaches its peak when it is welded by continuous welding. After 20mm, the rate of heat dissipation of the pipes slows down, resulting in the accumulation of heat and the expansion of pipes.

In conclusion, in the former 10 mm of the filling of the weld groove, there is large shrinkage no matter the welding is continuous or intermittent. Reducing the heat input is the only way to control the axial shrinkage in the former 10 mm of the filling of the weld groove. After 10 mm, axial shrinkage could be controlled by continuous welding. After 20 mm, the rate of heat dissipation of continuous welding slows down, resulting in the accumulation of heat and the expansion of pipes. And the curve of axial shrinkage of continuous welding falls.

4. Conclusion

(1) Axial shrinkage of pipes occurs mainly on the two thirds filler depth of the weld groove from the inner surface. In the former 20 mm of the filling of the weld groove, the amount of axial distortion is large. In 20~40mm, it reduces. After 40 mm, axial shrinkage barely exists, and appears mainly as expanding with heat and contracting with cold.

(2) In the two thirds filler depth of the weld groove from the inner surface, especially the one third filler depth of the weld groove from the inner surface, heat input should be kept low. In the one third filler depth of the weld groove from the outer surface, heat input could increase appropriately to improve the efficiency on condition that the quality of welding is assured.

(3) Continuous welding could be applied to control the welding distortion. In the former 10 mm of the filling of the weld groove, the amount of distortion is always large no matter the welding is continuous or intermittent. After 10 mm, continuous welding could be applied to reduce welding distortion on condition that interpass temperature is assured.

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References

[1] Karllsson L. Thermal stresses I, Amsterdam, Northholland, 1986.299-389.
[2] K Masubuchi. Theoretical Prediction in Joining and Welding. Osaka, Japan, 1996.71-88.
[3] J.A.Penso. Master's Thesis. The Ohio State University, Columbus, Ohio, USA, 1992.
[4] Y. Ueda. Trans. Japan welding Soc. 1971.2(2):90-100.
[5] Wang Rui, Liang Zhenxin, Zhang Jianxun. Transactions of The China Welding Institution, 2007. 28(3): 29-33.
[6] Deng Dean, Hidekazu Murakawa, Liang Wei. Computational Materials Science, 2006, 37: 269-277.
[7] Deng Dean, Murakawa Hidekazu. Computational Materials Science, 2006, 37: 209-219.
[8] Sattari-Far I, Javadi Y. International Journal of Pressure Vessels and Piping, 2007.
[9] Erika Hedblom. Lulea University of Technology: Department of Applied Physics and Mechanical Engineering, Division of Computer Aided Design. 2002.
[10] Xu Jijin, Chen Ligong, Ni Chunzhen. International Journal of Pressure Vessels and Piping, 2007, 84: 298-303.