Influence of Mn contents in 0Cr18Ni10Ti thin wall stainless steel tube on TIG girth weld quality

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Abstract. Three kinds of cold worked 0Cr18Ni10Ti thin wall stainless steel tubes with the manganese contents of 1.27%, 1.35% and 1.44% and the cold worked 0Cr18Ni10Ti stainless steel end plug with manganese content of 1.35% were used for TIG girth welding in the present investigation. The effect of different manganese contents in stainless steel tube on weld quality was studied. The results showed that under the same welding conditions, the metallographic performance of the girth weld for the thin wall stainless steel tube with the manganese element content 1.44% welded with end plug was the best. Under the appropriate welding conditions, the quality of the girth weld increased with the increase of the manganese content till 1.44%. It was found that in the case of the Mn content of 1.44%, and under the proper welding condition the welding defects, such as welding cracks were effectively avoided, and the qualified weld penetration can be obtained.. It is concluded that the appropriate increase of the manganese content can significantly improve the TIG girth weld quality of the cold worked 0Cr18Ni10Ti stainless steel tube.

Keywords: thin-wall stainless steel tube, Tungsten-arc Inert-Gas (TIG) welding, metallographic properties

1. Introduction

Austenitic stainless steel has excellent corrosion resistance and high temperature mechanical properties, and the radiation performance is stable. Therefore, it is widely applied for the parts of the nuclear industry, such as the reactor vessel, reactor components, cladding material of PWR associated core components and rods. Especially, the domestic developed austenitic stainless steel has been successfully applied in Qinshan nuclear power plant 300MW PWR as fuel cladding materials.

For a long time, in the manufacture of nuclear fuel elements the cracks and other welding defects easily generate during the tungsten electrode argon arc welding of girth seam for cold worked 0Cr18Ni10Ti thin-wall stainless steel, to produce which seriously affects the quality of product manufacturing. In order to solve the problems in the welding of thin-wall stainless steel tube, the effect of manganese content on the weld quality is discussed in detail in this study. The effect of manganese on the welding quality was analyzed by means of the tungsten electrode argon arc welding tests of three kinds of 0Cr18Ni10Ti thin wall stainless steel tube and the end plug.

2. Experimental

2.1. Welding requirements

The tungsten electrode argon arc welding was used to weld the three kinds of cold worked 0Cr18Ni10Ti thin wall stainless steel tube with the manganese contents of 1.27%, 1.35% and 1.44% and the cold worked 0Cr18Ni10Ti stainless steel end plug with manganese content of 1.35%. The weld and the heat affected zone shall not have cracks and other defects, only to allow the existence of a diameter of less than or equal to 0.25mm of the dispersed porosity [1]. The effective penetration should be no less than 90% of the minimum theoretical wall thickness of the cladding tube, and the melting depth should not be more than 1mm, the melting zone, the heat affected zone and the microstructure of the base metal. The tensile strength of welded joint shall not be lower than the lower limit specified by the tube. X ray inspection was used for metallographic examination.

2.2. Welding techniques

Stainless steel tube and end plug are both made of 0Cr18Ni10Ti. The stainless steel tube and the end plug are connected together by tungsten electrode argon arc welding, and the structure is schematically shown in figure 1. The outer diameter of stainless steel tube is 10 ± 0.03mm, the wall thickness is 0.48mm to 0.56mm, and the surface diameter of end plug is 9mm. The interference fit between the end plug and the stainless steel tube and the amount of interference shall be less than or equal to 0.015mm. Arc stability of non-melting tungsten electrode argon arc welding can be stable under the condition of less than 10A and the welding process is nothing more than splashing, weld forming beautiful. The model is suitable for the welding of cold worked stainless steel tubular material. Due to the thin wall thickness of stainless steel tube, the technical requirements of the weld penetration is not less than the minimum theoretical wall thickness of the stainless steel tube, therefore the TIG welding method is used to manufacture products.

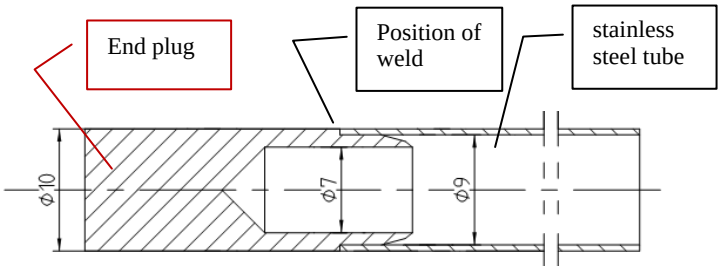

Figure 1. Schematic diagram of welding structure.

The selection of the welding parameters is important for the welding of thin-walled stainless steel material. It has been found that although TIG welding has the advantages for the welding of thin-wall stainless steel material, the tensile strength of weld joints, weld appearance, weld intergranular corrosion resistance can usually meet the requirements, however, in the inspection of the metallographic properties of weld, the welding cracks, lack of penetration and other defects have been often observed if the welding process is not appropriate. If the welding parameters are smaller, although the probability of crack can be reduced, it is easy to produce the problem of low penetration and low tensile strength. On the other hand, it is possible to increase the weld penetration depth, but the probability of crack is very high. Therefore, the actual production of the choice of welding parameters is very small. In the process of welding, the welding defects can be caused by any fluctuation, which seriously affects the quality of the products and the yield of the products.

2.3. Composition of the welding parts material

The stainless steel tube and the end plug used in the product are made of 0Cr18Ni10Ti stainless steel. The main chemical composition is listed in table 1. The addition of Manganese can improve the mechanical strength and medium temperature performance of the material, in addition to increase the solubility of N in metallographic phase. However, the effect of manganese content on the weld properties has been rarely studied. In order to solve this problem, considering the defects such as the

welding cracks, no penetration and so on, the influence of the manganese content on the metallographic properties of the welded joint the stainless steel is studied.

Table 1. Chemical composition of stainless steel tube (mass fraction,%).

C	Si	P	S	Mn	Ni	Cr	Ti	N	Co
≤0.08	≤1.00	≤0.035	≤0.020	≤2.00	9.00～12.00	17.00～19.00	≥5×C	≤0.037	≤0.05

2.4. Treatment for the welding parts

The end plug shall be cleaned by ultrasonic in NaOH solution,. After cleaning, the end plug is dried in the electric heating oven with drying temperature control in the temperature range of 80℃ to 100 ℃ for 30 - 60min, followed by wiping with the silk cloth.

The welding equipment with DC pulsed TIG welding power, and the output current is between 5A ~ 80A. The welding parameters for test are shown in table 2. The welding quality was examined by X-ray test and metallographic examination.

Table 2. Parameters of welding test.

Welding current (A)	Rotary speed of workpiece (r/min)	Welding time (s)	Cooling time (s)
45	12	5	10
50	12	5	10
55	12	5	10
60	12	5	10
65	12	5	10

3. Results Discussion

3.1. Effect of welding current on weld quality

Table 3. Effect of welding current on weld quality.

Mn content in stainless steel tube	Welding current	Quantity of sample	Weld appearance quality	X-Ray inspection	Metallographic quality of weld
1.27%	45A	2	ok	ok	lack of penetration
	50A	2	ok	ok	1 sample is ok,1 sample is lack of penetration
	55A	2	ok	ok	ok
	60A	2	ok	ok	1 sample is ok,1 sample is crack
	65A	2	ok	ok	ok
1.35%	45A	2	ok	ok	lack of penetration
	50A	2	ok	ok	ok
	55A	2	ok	ok	1 sample is ok,1 sample is lack of penetration
	60A	2	ok	ok	1 sample is ok,1 sample is crack
	65A	2	ok	ok	1 sample is ok,1 sample is crack
1.44%	45A	2	ok	ok	lack of penetration
	50A	2	ok	ok	ok
	55A	2	ok	ok	ok
	60A	2	ok	ok	ok
	65A	2	ok	ok	ok

The effect of welding current on the welding quality for three kinds of stainless steel pipe with the end plug is shown in table 3. The results in table 3 indicate that the girth weld of stainless steel pipe with 1.44% manganese content shows the best welding quality, while that of the stainless steel tubes with the manganese contents of 1.27% and 1.35% are not satisfied.

3.2. Discussion on weld metallographic properties

In technical requirements, it is specified that the effective penetration of weld shall not be less than 90% of theoretic wall thickness of cladding tube, while the penetration not more than 1mm; and the cladding the minimum theoretic wall thickness is 0.48mm and the effective penetration is acceptable when it is between 0.423mm and 1.0mm after welding cladding tube and end plug. Figure 2 shows the weld metallographic examination result, the weld penetration is increased with the welding current increasing, especially in the small current, three kinds of manganese content of different thin wall stainless steel pipe and the end plug weld penetration increase significantly, when the current is increased to 55A and more high numerical, weld penetration increases gently, tends to steady state, maintaining 0.513 to 0.545mm.

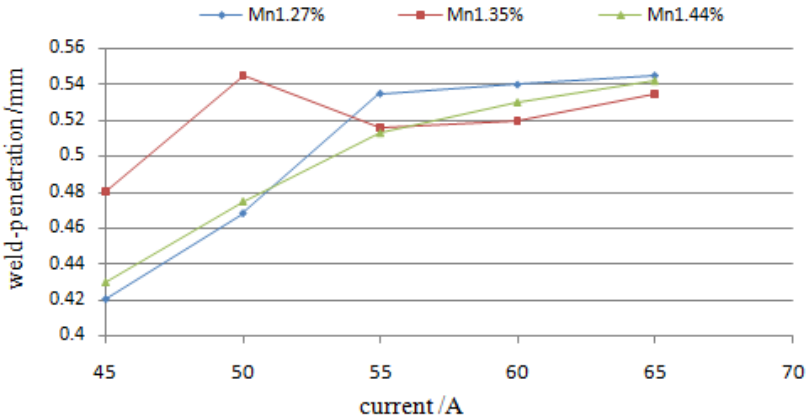

Figure 2. Welding penetration of three kinds of thin-wall stainless steel with different manganese contents with the welding current.

The typical weld penetration is shown in figure 3. Through the in-depth analysis of the microstructure of weld seam it is found that the partial values of the weld penetration meet 0.432 ~ 1.0mm, but no molten metal element in the stainless steel tube and the end plug joint root, forming a cavity, the weld penetration reaches 0.432 ~ 1.0mm in stainless steel tube and the end plug joint by stainless steel tube side, which leads to weld penetration index does not meet the requirements, leading to weld lack of penetration. Such phenomenon in the stainless steel tubes with manganese contents 1.27% and 1.35% is easy to cause lack of penetration when welding, but for the tube with manganese content 1.44%, the lack of penetration takes place only in the welding current 45A, due to the weld penetration smaller than the smallest penetration index 0.432mm.

In the process of girth welding cold worked 0Cr18Ni10Ti thin-wall stainless steel tube and end plug, it is very easy to have cracking in the weld. If the welding material is given, the welding energy plays a decisive role for the welding crack, while the welding energy is given, and the trend generating crack is different for the thin-wall stainless steel tube with different manganese contents. According to the test results, when girth welding thin-wall stainless steel tube with 1.27% manganese content and end plug within lower energy range, only incomplete penetration defect takes place and transverse and longitudinal cracks occur in the weld root. For welding thin-walled stainless steel tube with 1.35% manganese content and end plug, the trend of weld cracking is the same as that of the tube with 1.27% manganese content. When welding the thin wall stainless steel tube with 1.44% manganese content, the probability generating weld crack is much smaller. Only incomplete penetration takes place with smaller welding energy and no crack is produced with a larger range of welding energy.

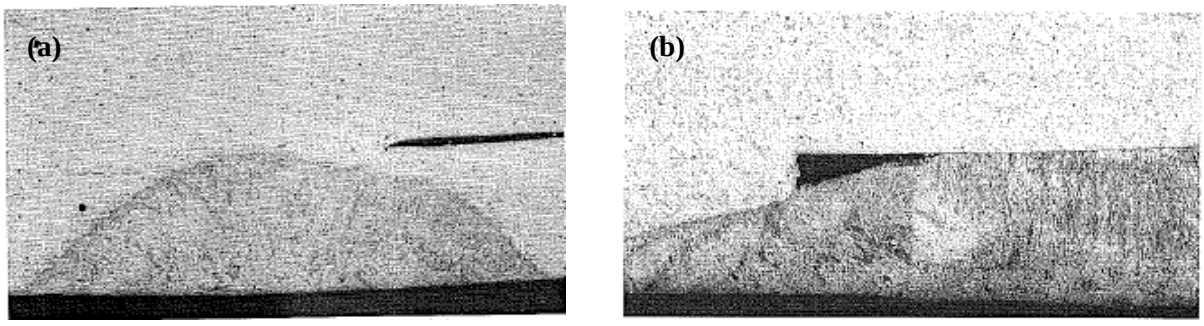

Figure 3. Changes of weld penetration in three kinds of thin wall stainless steel rings with different manganese content.
(a) Weld penetration 0.42mm, weld penetration is not enough, not weld penetration (1.44% manganese content of stainless steel pipe using 45A welding),
(b) Weld penetration 0.48mm, Cavity formation , not weld penetration (1.35% manganese content of stainless steel pipe using 50A welding),
(c) Weld penetration 0.545mm, weld penetration is enough (1.44% manganese content of stainless steel pipe using 60A welding).

When welding the thin wall stainless steel tubes with 1.27% and 1.35% manganese contents and end plugs by 60-65A welding current, the weld crack is very easy to generate. When welding the thin wall stainless steel tube with 1.44% manganese content and end plug by 60-65A welding current, no weld cracking generates. So, it shows that the different Mn content has an effect on the occurrence of welding crack. Under the condition that the content of the chemical composition of 0Cr18Ni10Ti thin wall stainless steel tube is less than or equal to 2%, the Mn content increased to 1.44%, which will significantly reduce the probability of cracking defect in the weld. Fig. 4 is a typical photo of welding crack.

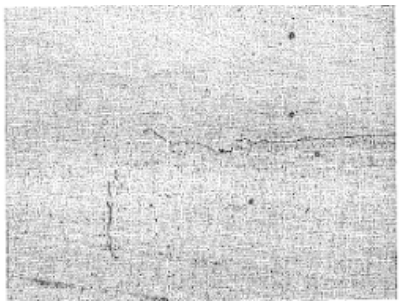

Figure 4. Weld crack defect.

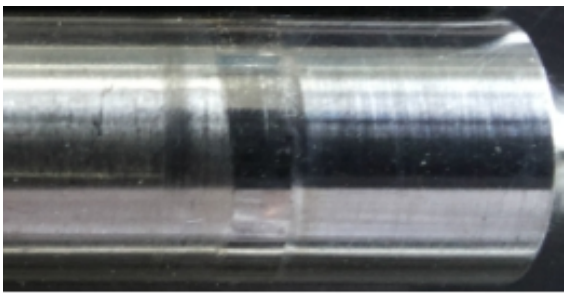

Figure 5. Weld appearance.

3.3. Weld appearance

The typical weld appearance is shown in figure 5. The appearance of thin-wall stainless steel tubs with 1.27%, 1.35% and 1.44% manganese contents and end plugs welded by the same welding energy is equivalent, with the smooth, silver-white and about 3mm uniform width weld and free of any superficial crack defect.

3.4. Weld X - ray examination

In order to check the existence of incomplete penetration, incomplete fusion and the porosity of diameter greater than 0.25mm, the whole girth weld is examined three times by X ray at 120 degree. The X-ray examinations show that no presence of porosity with diameter greater than 0.25mm is observed in the girth welds of the thin wall stainless steel tubes with the three manganese contents and end plugs. Test shows no porosity of diameter greater than 0.25mm is generated when welding the thin-wall stainless steel tubes with the different manganese contents and end plugs.

4. Conclusion

The content of manganese in the 0Cr18Ni10Ti thin-wall stainless steel tubes has a significant effect on the quality of the welds between welding of the stainless steel tube and the end plug. The 1.44% manganese content in thin-wall stainless steel tube is ideal for performing girth welding to end plug. Therefore in order to meet the welding quality requirement, the TIG welding current shall be controlled in the range of 50 - 65A and the Mn content in thin-wall stainless steel tube shall be 1.44%.

References

[1] Test method for weld seam of PWR fuel rods Metallographic examination and X ray inspection GB/T 11809