Effects of Chemical Compositions and Welding Methods on Tensile and J-R Properties of Austenitic Stainless Steel Welds

Ji-Hyun Yoon[a], Yong-Jun Oh[b], Bong-Sang Lee[a]
[a] *Korea Atomic Energy Research Institute, 150 Dukjin-dong Yusung-gu, Daejeon, Korea*
jhyoon4@kaeri.re.kr
[b] *Hanbat Nat'l Univ.,16-1 Dukmyung-dong Yusung-gu, Daejeon, Korea*

1. Introduction

The current design concept for nuclear piping is based on the elastic-plastic fracture mechanics technology, such as leak-before-break (LBB) analysis. The J-R fracture resistances as well as the tensile properties of the materials at operating temperature are prerequisite to perform LBB analysis to demonstrate flaw stability.

Even though the austenitic stainless steels generally exhibit excellent ductility, variations in toughness properties of surge line welds have been observed as a function of chemical composition and microstructure in previous studies. Some investigators have shown that Type 347 has a reduced fracture resistance compare to the unstabilized steels due to the presence of niobium carbides [1,2].

However, there has been relatively little research directed towards the influence of microstructure on the mechanical behaviors of the candidate materials for the surge line welds. The present work is a systematic investigation of the effects of microstructural changes, which were originated from the variations of the filler metals and welding methods, on the J-R and tensile properties of surge line welds.

2. Experimental

2.1 Materials and Specimens

The materials used in the present investigation were a total of seven austenitic stainless welds. They consisted of Type 347 GTAW (gas tungsten arc welding) welds, SMAW (shielded metal arc welding) welds and Type 316 GTAW welds sets and one Type 308L GTAW weld. The each set was composed of the high and low carbon alloyed steels.

Table 1. Chemical composition of various austenitic stainless steel welds.

	Cr	Ni	C	Nb	Mn	P	S	Mo	N
SMAW347	19.53	9.69	0.048	0.534	2.11	0.033	0.012	0.342	0.041
SMAW347L	19.32	9.75	0.033	0.584	2.32	0.034	0.010	0.382	0.041
GTAW347	19.2	9.35	0.047	0.56	1.37	0.025	0.015	0.18	0.043
GTAW347L	19.55	9.56	0.026	0.480	1.36	0.015	0.002	0.043	0.041
GTAW308L	19.73	9.78	0.016	0.011	1.93	0.026	0.011	0.151	0.027
GTAW316	19.11	11.89	0.029	0.012	1.64	0.019	0.002	2.33	0.021
GTAW316L	18.41	12.53	0.012	0.005	1.79	0.020	0.007	2.56	0.076

The uniaxial tensile specimens were the reduced rod type geometries. The gage length and the diameter of the specimen were 25mm and 6.25mm, respectively.

The side grooved compact tension type of 1-inch-thick specimens were used for measuring the J integral resistance (J-R) curves.

2.2 Experimental Procedures

The tensile tests were performed at 316°C (600°F) with a strain rate of 6.67×10^{-4}/s. The J-R curves were determined using the single specimen unloading compliance technique. The tests were conducted at 316°C (600°F) using a servo-hydraulic test machine in general accordance with the ASTM Standard E 1820-01.

Scanning electron microscopy, SEM (JEOL JSM-6300, 20kV) was used in conjuction with an energy dispersive spectrometer (EDS) to allow the observation of the microstructures and the primary identification of the various second phase particles. The electrolytic extractions of the precipitates were carried out for the quantitative analysis and identification of precipitates. The selected extractions were analyzed by X-ray diffraction to determine the structure of the precipitates.

3. Results and Discussion

3.1 Tensile Properties

The tensile test results were presented in Fig. 1. It was evident that the yield and tensile strengths of the Type 347 welds are higher than those of the other types of welds. On the other hand, the ductilities were lowered in Type 347 welds in average comparing to the other types of welds.

The strengths were decreased in low carbon welds comparing to the high carbon welds. It is well known that the strengths of these kinds of steels are closely related to carbon contents[3]. The phenomenon is explainable by the carbides induced precipitation strengthening mechanism.

A notable difference between the tensile properties of SMAW and GTAW welds was the elongation. The GTAW welds showed the higher ductilities.

The strength of Type 308L-GTAW weld was as low as those of 316L-GTAW welds. It might be due to the low carbon content in the weld.

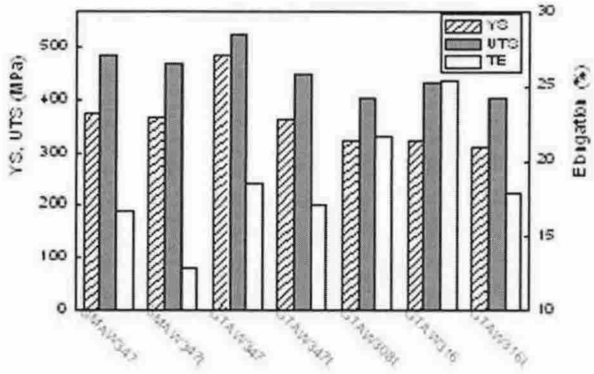

Fig. 1. Tensile properties of various austenitic stainless welds.

3.2 J-R Fracture Resistance Properties

The J-R fracture resistances of Type 347-SMAW welds were remarkably lower than those of GTAW welds regardless of carbon content levels as shown in Fig 2.

The Type 316 welds showed the higher J-R properties comparing to Types 347 and 308 welds. It was presumed that the high J-R fracture resistances of Type 316 welds were due their high ductilities.

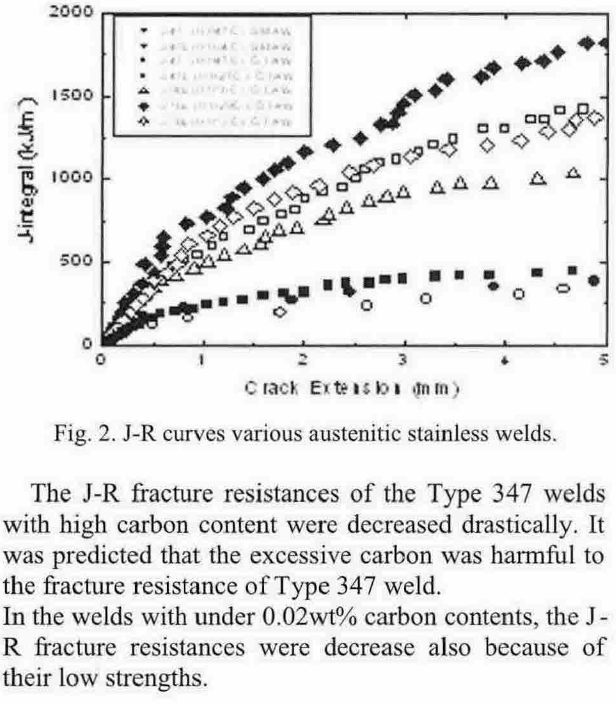

Fig. 2. J-R curves various austenitic stainless welds.

The J-R fracture resistances of the Type 347 welds with high carbon content were decreased drastically. It was predicted that the excessive carbon was harmful to the fracture resistance of Type 347 weld.

In the welds with under 0.02wt% carbon contents, the J-R fracture resistances were decrease also because of their low strengths.

3.3 Microstructural Analysis

The microstructural investigations were performed through the SEM-EDS and XRD analyses.

As shown in Fig. 3, micro-sized precipitates were formed at γ/δ interfaces and the micro-voids were initiated at matrix/precipitate interfaces in Type 347 welds. The precipitates were identified as Nb(C, N) as the results of SEM-EDS and XRD analyses for the extracted precipitates. It was presumed that coarse Nb(C, N) precipitates had deteriorated the fracture toughness of Type 347 welds.

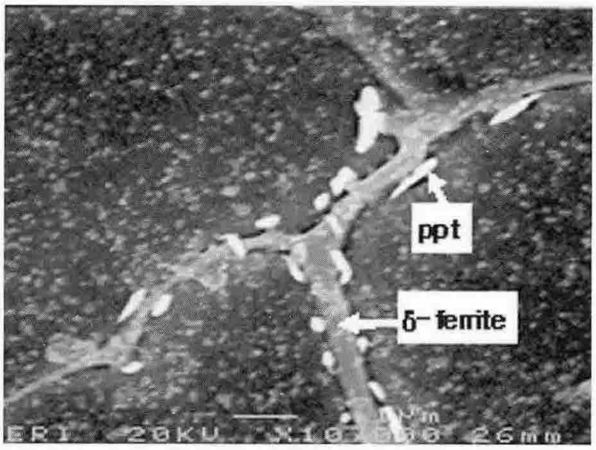

Fig. 3. SEM micrograph of Type 347 weld showing coarse pre-cipitates at γ/δ interfaces.

It was found that the coarse spherical manganese inclusions were formed in SMAW welds through the microstructural investigations. Typically, stainless steel welds fail by dimple rupture mechanism. The microvoids nucleate mainly at the second phase inclusions[4,5].

3. Conclusion

1) The tensile strengths of the Type 347 welds were higher than non-stabilized welds due to Nb (C, N) precipitate. The GTAW welds showed the higher ductilities comparing to the SMAW welds.

2) The J-R fracture resistances were decresed by excessive coarse ppts in Type 347 weld. In case of SMAW welds, mainly coarse inclusions deteriorated the fracture resistances

3) For the good combination of strength and J-R fracture toughness, Type 347-GTAW weld fabricated with the filler metal containing controlled carbon content was recommended.

REFERENCES

[1] W.T. DeLong, The Welding Journal July (1974), p. 273s.
[2] H. Muesch, Nuclear Engineering and Design Vol. 85 (1985) 155.
[3] W. M. Rainforth et al., Acta Materialia 50 (2002) 735-747.
[4] P. Balladon, J. Heritier and P. Rabbe, ASTM STP 791 (1983) II-496.
[5] T. C. Miller and T. L. Anderson, ASTM STP 1207 (1994) 87.