Title	MICROSTRUCTURE AND FRACTURE TOUGHNESS OF 316L HIGH NITROGEN WELD METAL PRODUCED BY HIGH-PRESSURE NITROGEN ARC WELDING(Materials, Metallurgy & Weldability)
Author(s)	Kikuchi, Yasushi; Kamiya, Osamu; Kumagai, Kazuo et al.
Citation	Transactions of JWRI. 1997, 26(1), p. 109-113
Version Type	VoR
URL	https://doi.org/10.18910/11452
rights	
Note	

MICROSTRUCTURE AND FRACTURE TOUGHNESS OF 316L HIGH NITROGEN WELD METAL PRODUCED BY HIGH-PRESSURE NITROGEN ARC WELDING †

Yasushi KIKUCHI*, Osamu KAMIYA, Kazuo KUMAGAI*** and Irwan HIDAYAT******

Abstract

Austenitic stainless steel of SUS316L was welded by the GMA process in high-pressure nitrogen atmospheres up to 6.1MPa(60atm). The fracture toughness of the weld metals was measured by means of the Charpy impact test at test temperature in the range from 77K to 290K. The influence of nitrogen content and microstructure on the toughness of the weld metal has been investigated. The content of nitrogen of GMA weld metal reached about 6700ppm at the maximum welding pressure of 6.1MPa. The Vickers' s hardness level increased from 225HV to 350HV with increasing nitrogen content up to 4000ppm. When the nitrogen content exceeded about 5000ppm, grain boundary fracture was easily caused by Cr_2N precipitation.

KEY WORDS: (High nitrogen steel) (Toughness) (Microstructure)

1. Introduction

Recently new austenitic stainless steels which contain over 1% of nitrogen have been developed. Such high nitrogen stainless steels possess high strength and toughness at low temperature and good corrosion resistance. The characteristics introduced by the nitrogen addition are affected by the welding process, however, and there are few studies about weldability and microstructural changes in the weld metal and fracture toughness (1). High nitrogen steels which contain in excess of 5000ppm have many interesting points for materials science.

The high nitrogen weld metal produced by welding in a high-pressure nitrogen atmosphere was investigated. The relationships between microstructure and fracture toughness were studied. Furthermore, the effect of post weld heat treatment (PWHT) was examined. An improvement of the low temperature fracture toughness was attempted.

2. Experimental Procedures

The chemical composition of SUS316L type austenitic stainless steel of thickness 12 mm and of the solid welding wire, SUSY316L, of diameter 1.6 mm are shown in **Table 1**.

The base metal was welded by the gas metal arc (GMA) process in a high-pressure nitrogen atmosphere using a welding chamber. The capacity of the chamber was 1.8m^3. Firstly, the chamber was evacuated below 10Pa and then nitrogen introduced up to the test pressures in the range of 0.1-6.1MPa. The base metals with X grooves were welded on both sides as shown in **Fig.1.** The welding condition maintained an arc length of 7mm, the welding current was 260A and the travel speed was 3.3mm/s.

The lattice parameters of weld metal and the precipitates were analyzed by the X-ray diffraction method (CuKα λ =1.5418 Å). The precipitates were gathered by a selective-potentiostatic-etching and electrolytic-dissolution (SPEED) method.

The Charpy impact test specimens were machined from welded joint as shown in Fig.1. Some of weld joints were heat-treated at a temperature of 1323K with a holding time of 1.8ks and at 1573K with a holding time

† Received on May 19, 1997

* Professor
** Associate Professor, Akita University
*** Professor, Akita University
**** Graduate Student, Akita University

Transactions of JWRI is published by Joining and Welding Reseach Institute of Osaka University, Ibaraki, Osaka 567, Japan.

Table 1 Chemical compositions and mechanical properties of materials used.

(mass %)

Materials	C	Si	Mn	Ni	Cr	Mo	N	O	Fe
Base metal SUS316L	0.018	0.70	1.22	12.08	17.38	2.03	0.0230	0.0035	Bal.
Weld wire SUSY316L	0.019	0.39	1.75	11.20	19.98	2.34	0.0169	0.0020	Bal.

Material	Proof stress	Tensile strength	Elongation	Hardness HV
SUS316L	252 MPa	547 MPa	63 %	217

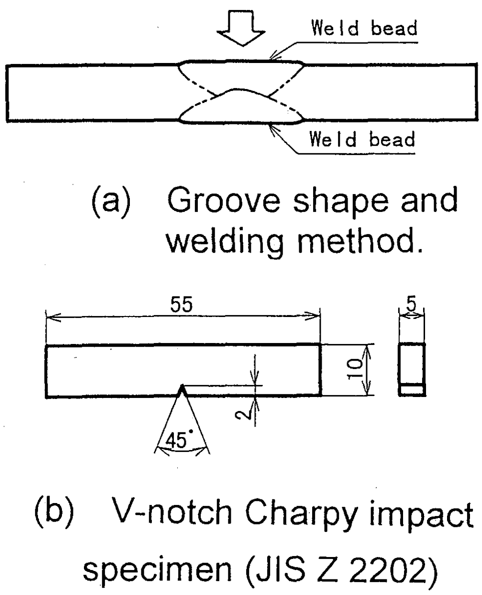

Fig. 1 Welded joint and Charpy impact test specimen.

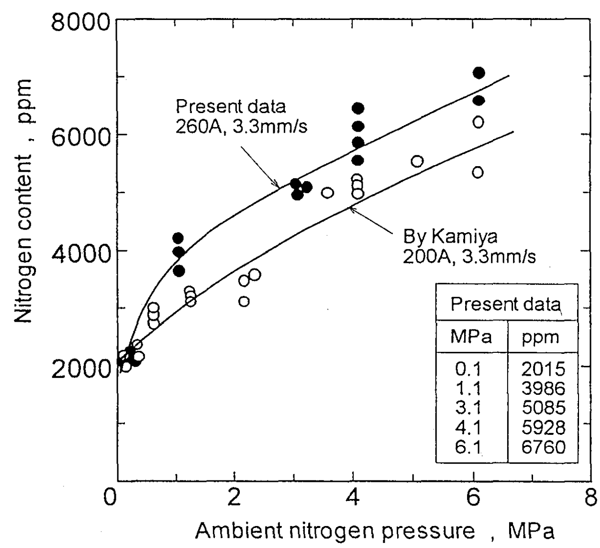

Fig. 2 Effect of the ambient nitrogen pressure on the nitrogen content of welded metal.

of 7.2ks. The test temperatures of the charpy impact test ranged from 290K to 77K. The fracture surfaces of tested specimens were observed by scanning electron microscopy (SEM).

3.Experimental result and discussions

3.1 Nitrogen content of weld metal

The relationship between the nitrogen content of the weld metal (as welded) and the nitrogen atmosphere pressure is shown in **Fig.2**. The nitrogen content in the weld metal reached 6760ppm with 6.1MPa of pressure. But this value does not match the theoretical equilibrium solubility. The weld metals have not had enough time to absorb nitrogen up to saturation level.

3.2 Microstructure of weld metal

Figure 3(a),(b) show typical examples of microstructural change in the weld metal. **Figure 3(a)** shows that the precipitates existed in the grain boundary with more than 5000ppm of nitrogen. **Figure 3(b)** shows the microstructure heat-treated at 1323K. In the

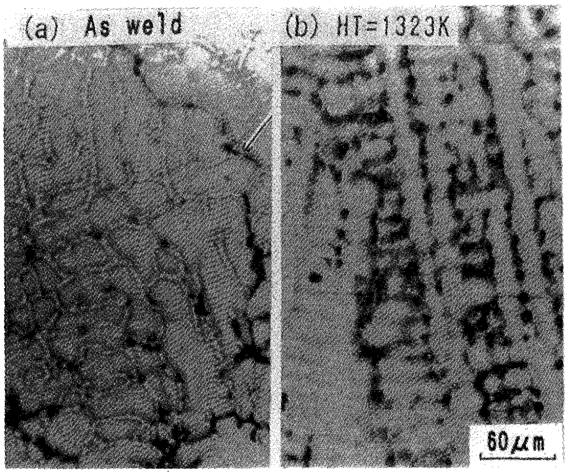

Fig. 3 Grain boundary precipitates of weld metal, as-welded at N=5085ppm (a) and heat-treated at 1323K(b).

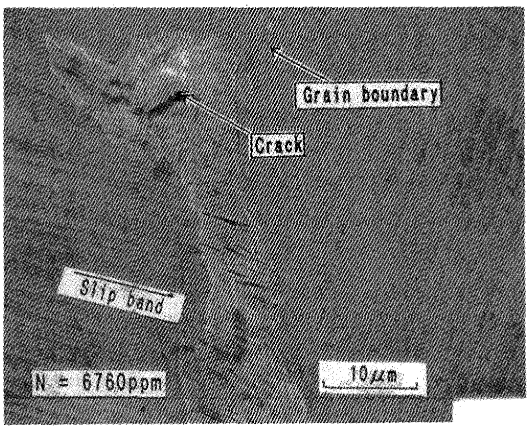

Fig. 4 Observation of crack and slip bands close to precipitate of weld metal.

case of nitrogen contents greater than 3000ppm the grain boundary precipitates increase.

Specimens with micro cracks were forced after the by 3 point bending test, as shown in **Fig.4**. In the previous report(2), it was reported that the relation between Cr_2N precipitate and matrix austenite phase showed good coherence. On the other hand, if the coherence is not satisfactory, the micro cracks will easily occur at such grain boundaries. It seems that the micro cracks reduced the impact values.

Figure 5 shows that hardness of the weld metal increases as the nitrogen content increases. It is thought that solid solution hardening and precipitation hardening are the cause.

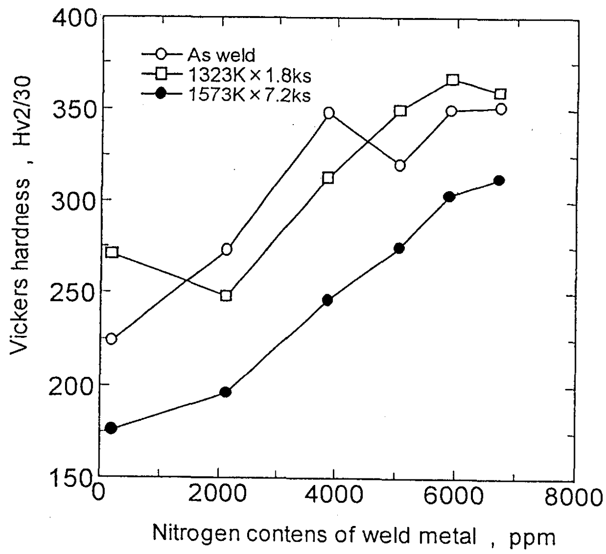

Fig. 5 Influence of nitrogen content and heat treatment on hardness of weld metal.

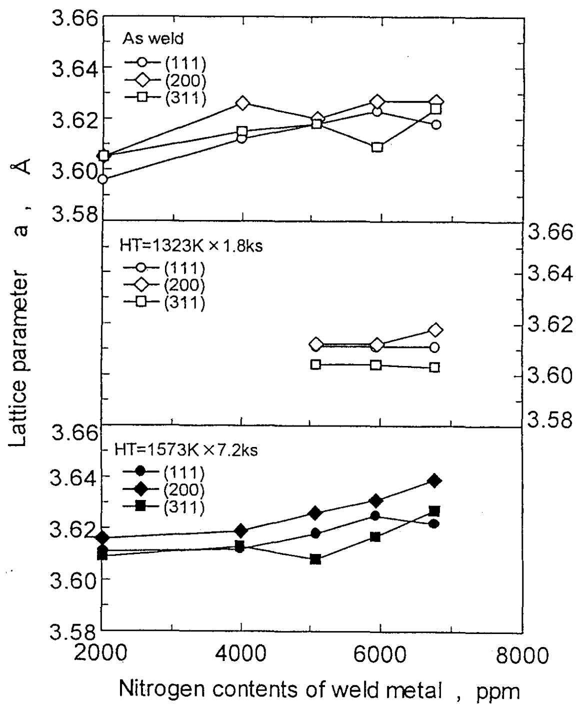

Fig. 6 Change of lattice parameter by interstitial solid solution of nitrogen.

Figure 6 shows a change of Lattice parameter. The lattice parameter shows a tendency to increase as the nitrogen content increases. The cause is thought to be that the nitrogen exists as interstitial solid solution in the

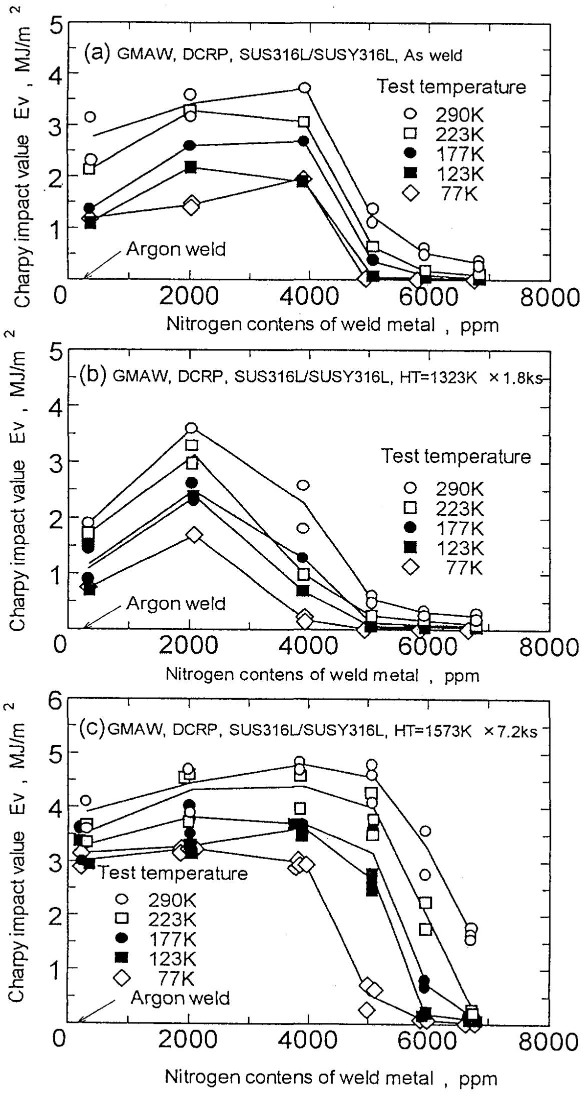

Fig. 7 Influence of nitrogen content and heat treatment on Charpy impact values.

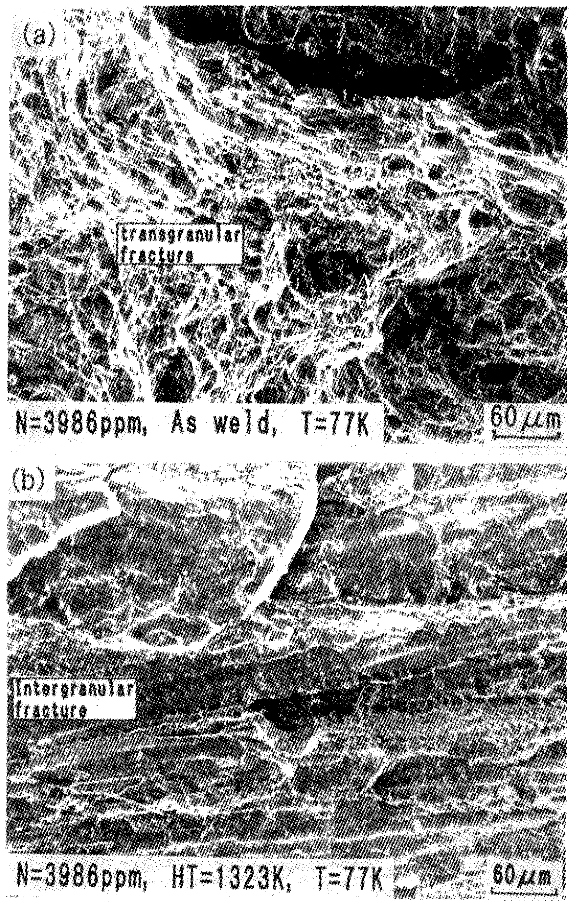

Fig. 8 Fractography of fracture surface Charpy impact specimen at low temperature (77K).

austenitic phase. The lattice parameter decreased after the heat treatment at 1323K. It is thought that interstitial solid solution nitrogen decreased by nitride precipitating in the weld metal as a result of heat treatment.

3.3 Fracture toughness by Charpy impact testing

Figure 7(a), (b) and (c) indicate the results of Charpy impact tests. Figure 7 shows that impact values rises with an increase of nitrogen content up to 4000ppm nitrogen. The impact value shows a maximum value at 4000ppm nitrogen, then a decrease. So, to the use of weld metal at low temperature should be avoided because of the brittle transition occuring in the weld metal.

Figure 7(b) indicates the effect of PWHT at 1323K on the impact values. In the case of higher nitrogen contents, more than 4000ppm, the impact value becomes remarkably low. On the other hand, **Fig.7(c)** indicates that PWHT at 1573K improves the impact values. Impact values at 77K and 4000ppm in particular show the improvement effect of PWHT on toughness.

In the case of at N=3986ppm, the fractography results are shown in **Fig.8**. On the fracture surface for the as-welded condition, dimple patterns of several micron diameter existed over the whole surface. Accordingly, it indicates that ductile fracture occurred. On the other hand, a brittle fracture was observed from the columnar structure in the weld metal heat-treated at 1323K as shown in **Fig.8(b)**.

Figure 9 indicates that the fracture occurred at precipitates along the grain boundary. It was clear that the toughness was reduced by precipitates.

Figure 10 shows the shape of precipitates gathered by the method of SPEED and the result of X-ray

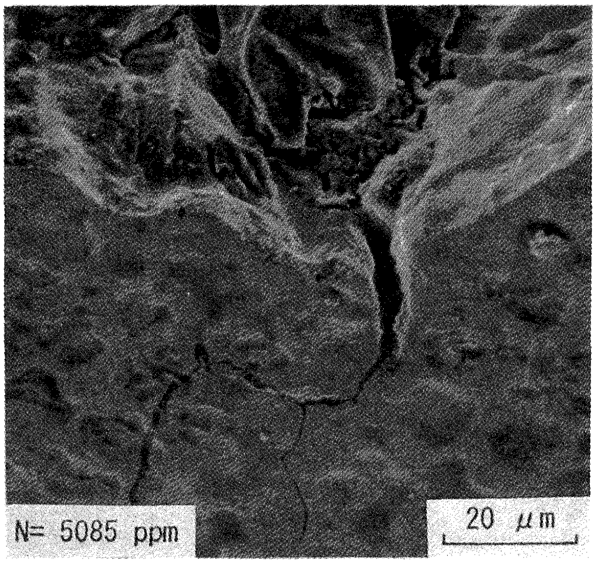

Fig. 9 Simultaneous observation of microstructure and fracture surface.

diffraction. It was clear that the precipitate consisted of flaky Cr_2N.

According to the phase diagram of Fe-18Cr-8Ni-N (3), the composition and temperature of the high nitrogen weld reaches the Cr_2N precipitation line during the welding process and allows the formation of Cr_2N precipitates. At less than 4000 ppm nitrogen content, the precipitates become soluble again through the heat treatment at the temperature of 1573K. Heat treatment at 1323K is in the Cr_2N precipitation range and the toughness deteriorates but the temperature of 1573K is the γ single phase range and the toughness improves.

4.Conclusions

The fracture toughness of high nitrogen weld metal was examined.

(1) The hardness of weld metal increases with increasing nitrogen content.

(2) The lattice parameter of the weld metal increases with nitrogen content.

(3) Toughness increases in case nitrogen contents of less than 4000ppm. When the nitrogen content exceeds 4000ppm, Cr_2N nitride is formed at grain boundaries, and brittle fracture occurs.

(4) In case of heat treatment at 1323K, the grain boundary precipitates of Cr_2N increase and the toughness value falls. For heat treatment at 1573K, the toughness value is improved because the precipitates are redissolved in the matrix.

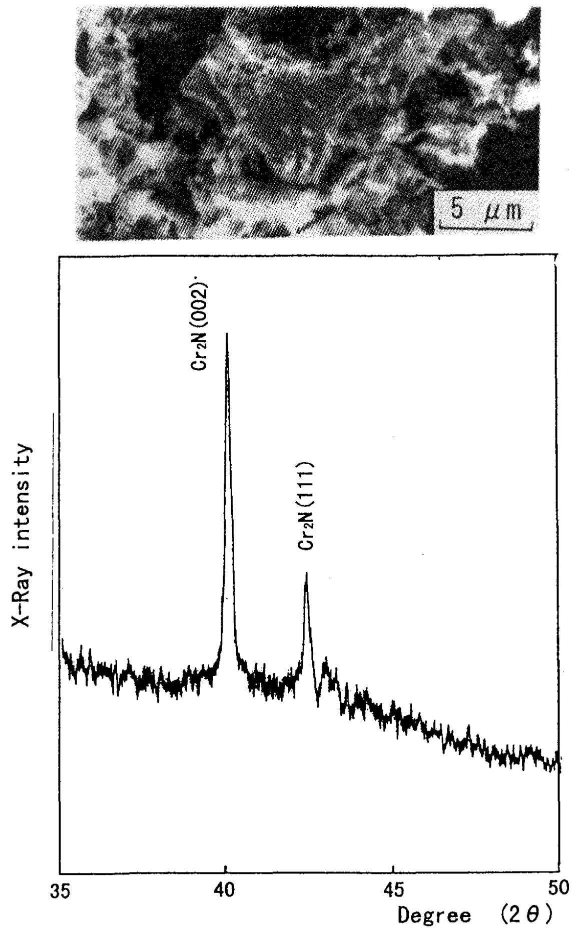

Fig. 10 Shape of precipitates and the result of X-ray diffraction.

The authors thanks to Mr.Ryuichi Kato, Mr.Fumio Ashihara and Mr.H.Kobayashi of Akita university for their cooperation.

References

1) Y. Kikuchi, F. Matsuda, O. Kamiya and G. Janak "TIG and MIG Welding of Austenitic Stainless Steel in Dry Hyperbolic Nitrogen Atmosphere" Proc.19th Inter. Welding Congress '94 Bratislava,1994, 120-128.

2) T.Tanaka, M. Kikuchi and R. Tanaka "Electron Microscopic Observation of Cr_2N Precipitated in 25%Cr-28%Ni-2%Mo Austenitic Steels Containing Nitrogen" Journal of Japan Metal Society, Vol.41, No.11,1977, 1145-1153.

3) T.Matsumoto & Y. Imai "Structural Diagrams and Tensile Properties of the 18% Cr-Fe-Ni-N Quaternary System Alloys" Journal of Japan Metal Society, Vol.33, No12, 1969, 1364-1371.