J. Plasma Fusion Res. SERIES, Vol. 5 (2002) 527–531

Development of Laser Welding Technology for Vanadium and Its Alloys

HEO Nam-Jin, NAGASAKA Takuya[1], MUROGA Takeo[1], NISHIMURA Arata[1], SHINOZAKI Kenji[2] and TAKESHITA Noriyuki[2]
Department of Fusion Science, The Graduate University for Advanced Studies, Toki 509-5292, Japan,
[1] National Institute for Fusion Science, Toki 509-5292, Japan,
[2] Department of Mechanical System Engineering, Graduate School of Engineering, Hiroshima University, Higashi Hiroshima 739-8527, Japan

(Received: 12 December 2001 / Accepted: 19 June 2002)

Abstract

The laser welding technology for vanadium and its alloys, eliminating contamination with impurities, was developed using YAG laser beams introduced into an environmental control box. The use of quartz glass and supplying substitution gas into the box made it possible to obtain the weldments without pickup of impurities. The welding reducing the contamination with the impurities was achieved by applying the substitution argon gas with the flow rate of 100 L/min.

Keywords:

low activation structural material, vanadium, YAG laser welding, environmental control

1. Introduction

V-4Cr-4Ti alloys are attractive candidates of low activation structural materials for fusion reactors, due to their low induced radioactivity, good resistance to neutron radiation damage and good elevated-temperature strength [1-4]. Two major remaining issues for applying the vanadium alloys for fusion reactors are the technology for production of large heat vanadium alloys and the development of welding method, which is the key requisite for fabricating structures. Some large heats were fabricated by US-DOE [5-6], and recently, high purity V-4Cr-4Ti alloys (NIFS- HEAT-1 and 2) were fabricated by National Institute for Fusion Science (NIFS) in Japan [7-8].

The laser welding is a promising technique because of its flexibility for field, lenient require- ment for atmospheric control and capability of deep penetration with less input. Some researches for the laser welding on vanadium alloys have been carried out. However, previous studies showed that pickup of impurities took place during welding, resulting in property degradation of the joint [9-11].

It is well known that impurities such as oxygen, nitrogen carbon and so on have various effects on properties of pure vanadium and its alloys [12-14]. To establish the welding technology for obtaining the sound weldments, it is necessary to control the environment during the welding for preventing the contamination with the impurities. The purpose of this study is to develop the laser welding technology for vanadium and its alloys reducing the contamina- tions to the acceptable level.

2. Experimental Procedure

In this study, the specimen plates of 4 mm thick are

Corresponding author's e-mail: heonj@nifs.ac.jp

prepared for laser welding by cold-rolling unalloyed vanadium to the reduction of 60% in thickness. Unalloyed vanadium was chosen as a material because the hardness of unalloyed vanadium is sensitive to the impurity level and was evaluated systematically [15].

To prevent the contamination with interstitial impurities, such as hydrogen, oxygen, nitrogen, carbon, etc. an environmental control box capable of supplying high-purity argon gas (99.9999%), and ventilating the fume was designed and fabricated, as shown in Fig. 1. The environmental control box has two nozzles for cleaning the specimen and two gas suppliers for substitution of the atmosphere. The gas introduced through the nozzles 1 and 2 blows out the fume produced during the welding process on the top (nozzle 1) and the bottom (nozzle 2) surface, respectively.

During the welding, each nozzle supplied argon gas of 50 L/min. The flow rate of the substitution gas varied from zero to 500 L/min in total. The laser beam came in the box through the quartz glass window with the thickness of 2.3 mm.

Bead-on-plate welds were produced on the 4 mm-thick plate, using 2.0kW YAG laser in the welding condition of 1.8kW continuous wave and traveling speed of 0.5 m/min. Focal point was the surface of the specimen, in which spot size of the laser light was 0.5 mm in diameter.

To estimate the pickup of interstitial elements in the weldments, chemical analysis and hardness measurement after the post-weld heat treatment at 673 and 1273K for an hour were carried out. Microstructural observations were also carried out.

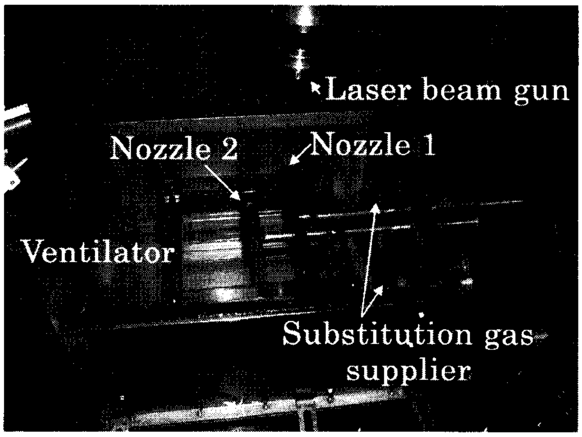

Fig. 1 Inside of an environmental control box designed and fabricated for the present experiment.

3. Results

Figure 2 shows the outward appearance of the beads for three welding environments. When welded in the air and with supplying the argon gas of 50 L/min each with two nozzles, the bead was colored due to contamination with impurities. However, by use of the additional supply of the substitution gas of 300 L/min color due to the contamination was not detected.

Figure 3 shows the cross sectional microstructure of the weld zone in the condition of the laser power of 1.8 kW and welding speed of 0.5m/min. Microstructure observation showed that the grains in the

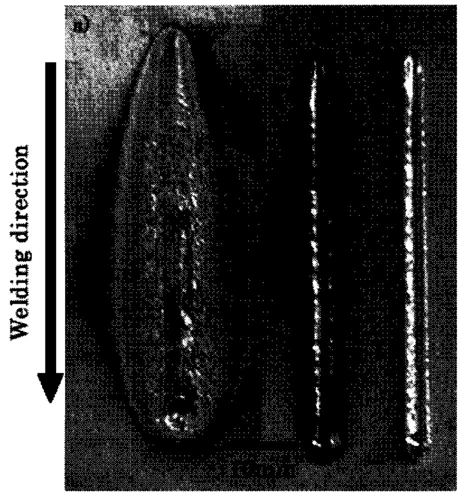

Fig. 2 The outward appearance of the weld beads for three cases of the welding environment.
a) in the air
b) nozzles: 100 L/min, substitution: 0 L/min
c) nozzles: 100 L/min, substitution: 300 L/min

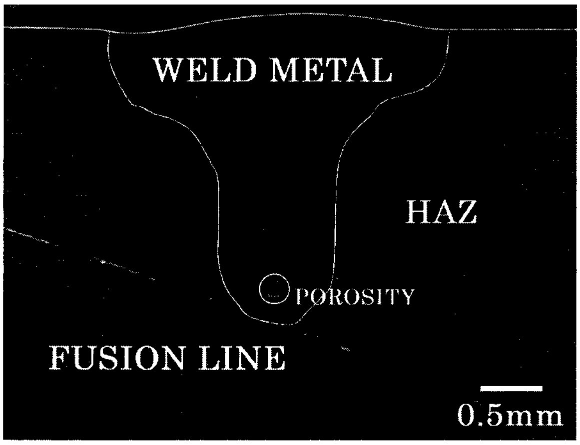

Fig. 3 Cross sectional microstructure of the weld zone.

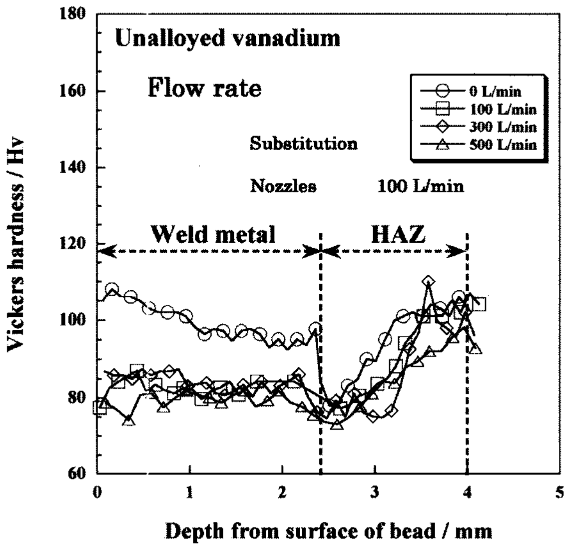

Fig. 4 Effect of the flow rate of the substitution gas on depth profile of hardness.

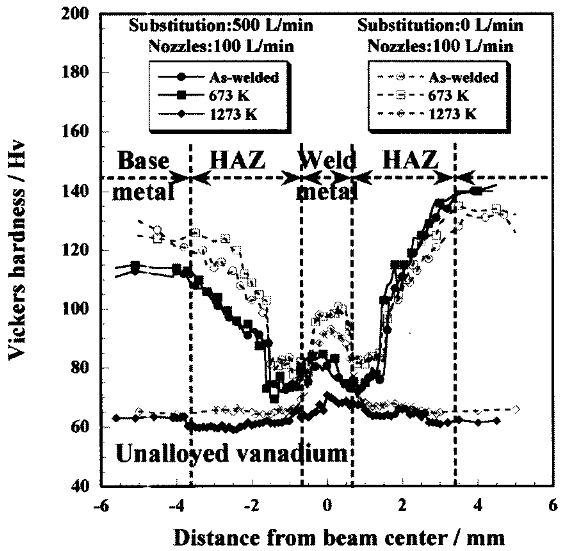

Fig. 5 Effect of the post-weld heat treatment on hardness. Hardness was measured at 1.2 mm in depth position.

Table 1 Oxygen and nitrogen levels before and after the laser welding in various flow rate of the substitution gas. (mass ppm)

Flow rate (L/min)		0	100	200	300	500
	Before	After				
O	69	85	76	106	105	82
N	94	170	93	81	92	115

weldment are elongated as a result of the heat transfer during the resolidification. On the other hand, the grains in heat-affected zone (HAZ) are smaller and equiaxed. The penetration depth was about 2.4 mm, and porosities were observed at the bottom of the weldment.

Figure 4 indicates the hardness change with the distance into weld zone from the surface of the bead. The relatively small variation in hardness to the depth of 2.2mm from the surface followed by a sudden drop, in the case without the substitution gas, implies that impurities introduced from the surface during the welding were almost homogen- eously distributed as a result of mixture driven by thermal convection.

Figure 5 shows the hardness of the specimen as-weld and annealed at 673K and 1273K for an hour in a vacuum ($<10^{-6}$ Torr) in the cases with and without the substitution gas supply. The hardness was measured at 1.2 mm thick from the surface of the bead. In case of the as-welded condition, com- pared with the hardness of the base metal before annealing, those of the weld zone were significantly decreased, regardless of the supply of substitution gas, because of the recovery of the dislocations induced by the cold rolling.

In the both cases with and without the supply of substitution gas, annealing at 673K did not change hardness. The decrease of hardness in the base metal of both specimens by annealing at 1273K is the result of the recovery of the dislocations induced by the cold rolling. The hardness at and near the center of the weldment relative to that of the base metal after annealing at 1273K is small and large in the cases with and without the sub- stitution gas supply, respectively. The significant increase in hardness at and near the center of the weldment in the case without the substitution gas supply seems to be due to contamination.

Table 1 indicates the result of chemical analysis before and after laser welding. The samples for the analysis were extracted from the molten zones. Without the substitution gas supply, the nitrogen level in the weldment increased significantly. The reason seems to be that nitrogen was picked up from the air remaining in the environmental control box during the laser welding. The contamination of impurities, such as oxygen or nitrogen, was very small with the flow rate of 100 L/min and above.

4. Discussions

It is known that hydrogen may be introduced during welding of vanadium alloys, enhancing the

Table 2 Hardness change with impurity levels and post-weld heat treatment.
The predicted hardness change according to the impurity level and the previous measurements [15] are also listed.

	Each nozzle: 50 L/min Substitution: 500 L/min	Each nozzle: 50 L/min Substitution: 0 L/min
Chemical analysis (mass ppm)	Oxygen: 82, Nitrogen: 115	Oxygen: 85, Nitrogen: 170
Predicted ΔHv according to [15]	3.3	10
ΔHv (as-welded)	12	29
ΔHv (annealed at 673 K)	15	28
ΔHv (annealed at 1273 K)	2	19

hardness [16]. The hardening by hydrogen, however, was shown to recover by annealing at 673K in vacuum [16]. The fact that hardness did not change by annealing at 673K, as shown in Fig. 5, implies that contamination with hydrogen was negligibly small in the present study.

Since the precipitate was not formed in unalloyed vanadium unlike vanadium alloys, the impurities picked up during the laser welding are expected to exist as interstitials in the fusion zone. In the previous study, hardness increase with increasing the impurity levels in unalloyed vanadi- um and its alloy was quantitatively evaluated [15,17].

Table 2 shows the hardness change, which is the average hardness of the area extracted for the chemical analysis relative to the hardness of full-anneal base metal (65Hv), as-weld and after post-weld heat treatment in the cases with and without the substitution. The table 2 also shows the predicted hardness change according to the impurity level and the previous hardness measure- ment of vanadium doped with oxygen and nitrogen [15]. Here ΔHv of 0.06 Hv per 1 mass ppm O and 0.12 Hv per 1 mass ppm N were used for the prediction.

As shown in Table 2, there is no difference in hardness between as-welded and annealed at 673 K. This fact indicates that the pick-up of hydrogen in welding process did not occur. Hardness change as-welded and annealed at 673K is much larger than the predicted values. The hardness increase after welding is due to the introduction of impurities, dislocations and thermal stress during the welding process. Annealing at 1273K results in the recovery of the dislocations and thermal stress introduced, inducing the decrease in hardness.

In the case of supplying substitution gas, the value of hardness increase is in good agreement with that by the prediction. However, without the substitution gas, measured hardness was higher than predicted. The impurity segregation may be responsible for the remaining hardness.

From the relations between the increase of hardness and the pick-up of the impurities, the present result indicates that the substitution gas supply with the flow rate for the substitution gas of 100 L/min is enough for preventing the contamina- tion during the welding.

5. Conclusions

To develop the laser welding technology for vanadium and its alloys without the contamination of impurities, YAG laser welding was carried out with controlling the welding environment.

1) The contamination of impurities during the welding process can be predicted using unalloyed vanadium and with hardness measurements.

2) Simple environmental control box with the nozzles for blowing out the fume and the supply of substitution gas made it possible to obtain the weld zone reducing the contamination of the impurities.

References

[1] R.J. Kurtz *et al.*, J. Nucl. Mater., **283-287**, 70 (2000).

[2] S.J. Zinkle *et al.*, J. Nucl. Mater., **258-263**, 205 (1998).

[3] H. Matsui *et al.*, J. Nucl. Mater., **233-237**, 92 (1996).

[4] B.A. Loomis *et al.*, J. Nucl. Mater., **212-215**, 799 (1994).

[5] H.M. Chung *et al.*, Fusion Materials Semi-annual Progress Report, DOE/ER-0313/17, 178 (1994).

[6] W.R. Johnson *et al.*, J. Nucl. Mater., **258-263**, 1425 (1998).

[7] T. Muroga *et al.*, J. Nucl. Mater., **283-287**, 711 (2000).

[8] T. Nagasaka *et al.*, FUSION TECHNOLOGY **39**, 659 (2001).

[9] H.M. Chung *et al.*, Fusion Materials Semiannual Progress Report, DOE/ER-0313/20, 59 (1996).

[10] Y. Yan *et al.*, Fusion Materials Semiannual Progress Report, DOE/ER-0313/28, 17 (2000).
[11] Y. Yan *et al.*, Fusion Materials Semiannual Progress Report, DOE/ER-0313/29, 50 (2000).
[12] D.R. Diercks *et al.*, J. Nucl. Mater., **141-143**, 1117 (1986).
[13] H.M. Chung *et al.*, J. Nucl. Mater., **239**, 139 (1996).
[14] M.L. Grossbeck *et al.*, J. Nucl. Mater., **258-263**, 1369 (1998).
[15] T. Nagasaka *et al.*, J. Nucl. Mater., **283-287**, 816 (2000).
[16] T. Nagasaka *et al.*, J. Nucl. Mater., to appear.
[17] N-J. Heo *et al.*, J.Nucl. Mater., to appear.