IMPURITY STUDIES OF GAS TUNGSTEN ARC WELDING OF VANADIUM ALLOYS –

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OBJECTIVE

The goal of this research is to acquire a fundamental understanding of the metallurgical processes in welding vanadium alloys and to develop techniques for joining structural components made from vanadium alloys.

SUMMARY

An improved getter system has been installed on the welding glove box since progress was last reported. Gas tungsten arc (GTA) welds using both oxygen and hydrogen getters resulted in very low oxygen levels but very high hydrogen levels in V-4Cr-4Ti. Charpy impact testing, nonetheless, determined a DBTT lower than previously achieved. The first weld with a DBTT at room temperature was made. Erratic results following post-weld heat treatments or low-temperature outgassing treatments were previously attributed to hydrogen cracking. It is now believed that this behavior is not so erratic and might result from precipitation. Transmission electron microscope studies have been initiated to study the unusual behavior.

INTRODUCTION

The susceptibility of vanadium alloys to interstitial embrittlement is most pronounced in welding. In welding, it is usually not possible to achieve the ultra-high vacuum necessary for high temperature processing. In addition to the contamination from the welding environment, the rapid heating and cooling associated with welding quenches interstitials in the lattice. Thicker plates result in lower cooling rates so that techniques used for welding thin sheet might be useless for thicker plates required for building an actual structure. Electron beam (EB) welding, which can be used to successfully weld vanadium alloys is limited by the size of the vacuum chamber available. Although EB welding is likely to be used in joining small parts, it will never be practical for welding the large structures associated with fusion devices.

For the present study, 6.4 mm plate of V-4Cr-4Ti (Wah Chang heat 832665) has been selected as a reasonable thickness for which to study welding methods. When methods have been developed to weld 6.4 mm plate, thicker sections can be researched. However, since unacceptable embrittlement is observed after GTA welding of 6.4 mm plate, beneficial research can be conducted on this material.

EXPERIMENTAL RESULTS AND DISCUSSION

The welding methods for GTA vanadium alloy welding have been previously described.[1] The

primary test method to evaluate brittleness of the welds remains the Charpy impact test. Static fracture toughness tests on pre-cracked Charpy specimens are expected to be done in the future. However, since a DBTT below room temperature has not yet been achieved, such tests will be deferred in order to avoid the necessity for pre-cracking at elevated temperatures. Previously, oxygen levels below 1 wt. ppm were achieved in the glove box atmosphere by the addition of a molecular sieve filter combined with a hot titanium getter.[1] In doing so the oxygen contamination level was lower than previously achieved, but the sample, GTA 16, was contaminated with hydrogen to a level of 3000 at. ppm.[1] To alleviate this problem, an additional getter was added to the system. Unlike the titanium getter which was part of a recirculating gas system, the hydrogen getter was placed in the glove box directly. It consisted of a Zr-Al alloy deposited on a constantan substrate.[1] The getter is heated to dissolve the oxide surface layer to expose a clean metal surface. The getter is then cooled to dissolve hydrogen.

Using the hydrogen getter system, the oxygen level in the glove box atmosphere was off scale using a zirconia detector. An additional weld on V-4Cr-4Ti, GTA 17, was made using these conditions. In this case, the hydrogen level in the fusion zone was measured by inert gas fusion analysis to be 5000 at. ppm. The impurity concentrations in the weld and the welding atmosphere are shown in Table 1 for this weld and the previous weld, GTA 16. This high level of hydrogen was attributed to an incorrect use of the hydrogen getter. Since there was no thermocouple on the hydrogen getter, its temperature could only be monitored by color. Because the substrate begins to melt above 800°C, the getter had to be heated conservatively, which was probably the cause of the poor performance of the getter in absorbing hydrogen.

Table 1. Impurity concentrations in welding atmosphere and in the weld fusion zones

		Welding Atmosphere		Fusion Zone Concentration			
Weld	**PWHT**	**Oxygen Wt. ppm**	**Moisture Wt. ppm**	**Oxygen Wt. ppm**	**Nitrogen Wt. ppm**	**Hydrogen Wt. ppm**	**DBTT °C**
GTA 16	AS WELDED	0.8	25	370	107	63	85
GTA 16	400°C/1h						38
GTA 17	AS WELDED	<<1	<1	347	99	99	20
GTA 17	400°C/1h					1.9	

Charpy impact tests were performed on weld GTA 17 despite its high level of hydrogen contamination. A DBTT of 20°C was obtained, the lowest value for at GTA weld in 6.4 mm

[1]Manufactured by SAES Getters, Milan, Italy

vanadium alloy plate. Not only hydrogen interstitial hardening, but hydrogen embrittlement from stress induced hydride formation could have occurred at such a high level of hydrogen resulting in a reduced DBTT do to the hydrogen alone. To investigate this possibility, samples were outgassed at 400°C for one hour. Theresulting Charpy impact curves obtained before and after the outgassing treatment are shown in Fig. 1. As can been seen from the curve for the as welded samples, the data fit the curve reasonably well, giving a well defined DBTT. In the case of the outgassed samples, the data are badly scattered. Previously, this phenomenon has been attributed to pre-existing cracks resulting from hydrogen embrittlement. The proximity to the hydride solvus is also shown in Fig. 1. Application of a stress could shift the solvus to a higher temperature resulting in cracking significantly above the stress-free hydride solvus.[2] However, weld GTA 16, which had 3000 at. ppm hydrogen, was treated similarly. The Charpy impact curves for this weld appear in Fig. 2. As with GTA 17, the as welded curve is well behaved, in this case, giving a DBTT of 85°C. Following outgassing at 400°C for one hour, the data are again scattered. However, comparison of the curves for the two welds shows that it is not random scatter. There is a dip in the Charpy energy curve at 50 and 100°C for GTA 17 and GTA 16, respectively. Other welds have shown a similar phenomenon following higher temperature heat treatments. Weld GTA 10 exhibits dips in the Charpy energy curves between 100 and 150°C following post-weld heat treatments of 750, 850, and 950°C for two hours.[3] In all cases of unusual lower shelf behavior, the fracture surfaces exhibit entirely cleavage fracture. However, this would also be expected to result from hydrogen embrittlement. Nonetheless, this phenomenon of unexpected dips in the Charpy energy curves is now believed to be a real effect.

A precipitation phenomenon is a possible explanation for the effect. Transmission electron microscopy (TEM) is being use at the present time to investigate the microstructure. A brittle second phase could explain a high DBTT. However, it is difficult to explain a dip in the Charpy energy curve in terms of a brittle precipitate. As shown in Figs 1 and 2, the ductility returns at a lower temperature. This phenomenon is observed in the case of hydrogen embrittlement, but even the 400°C heat treatment in an vacuum has been shown to reduce the hydrogen concentration to below 2 wt. ppm.

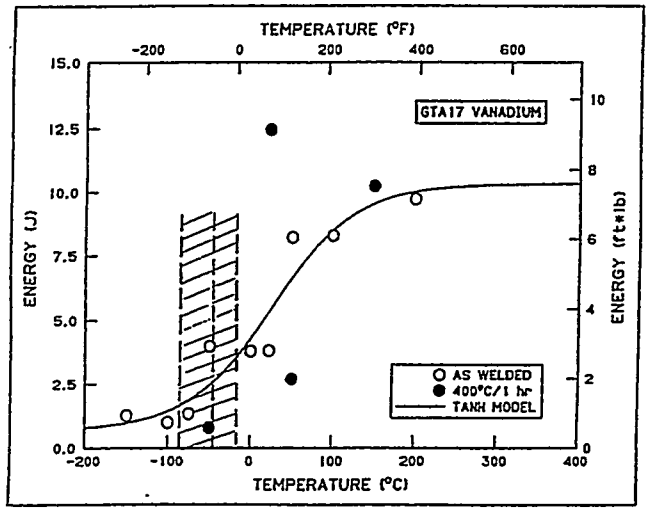

Figure 1. Charpy impact curves for weld GTA 17 before and after outgassing treatment to remove hydrogen. The cross hatched area is the zone of hydride formation under stress.

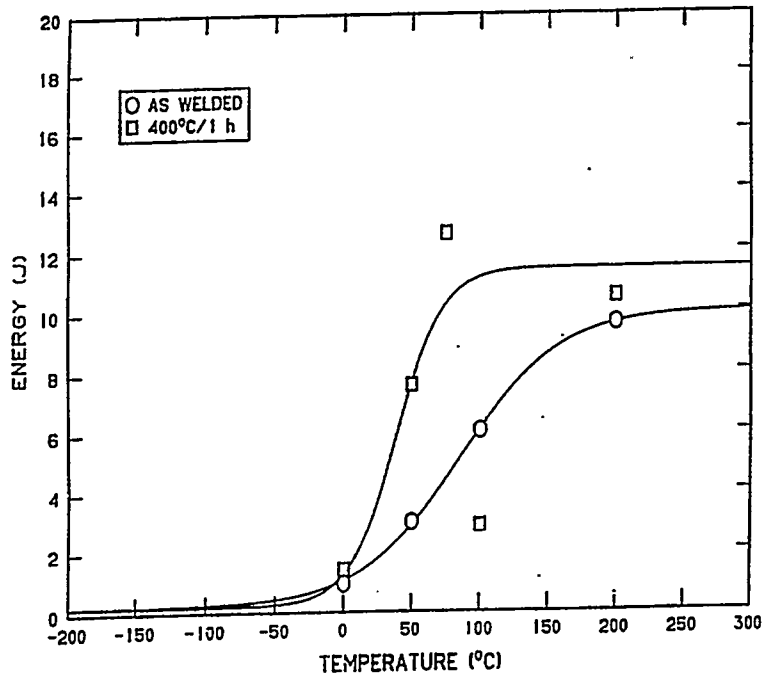

Figure 2. Charpy impact curves for weld GTA 16 before and after outgassing to remove hydrogen

FUTURE DIRECTIONS

Two improvements have been made to the welding glove box. A thermocouple has been installed on the hydrogen getter so that it may be properly activated at a sufficiently high temperature. In addition, a gas chromatograph has been installed to monitor the hydrogen concentration in the glove box atmosphere. A quadrapole mass spectrometer residual gas analyzer will also be added to the glove box system. In the future, a weld will not be made when the hydrogen concentration is high.

CONCLUSIONS

1. Reduction of oxygen concentration in the GTA welding atmosphere reduces the DBTT. A DBTT of room temperature has been achieved.

2. A strongly gettered system is necessary to reduce both oxygen and hydrogen to levels below 1 wt. ppm.

3. The unexpected dips in the Charpy energy curves, previously attributed to hydrogen embrittlement cracking, are believed to be related to precipitation during post-weld heat treatments or outgassing heat treatments.

REFERENCES

1. M.L. Grossbeck, J.F. King, D.J. Alexander, and G.M. Goodwin, "Recent Progress on Gas Tungsten Arc Welding of Vanadium Alloys," Fusion Materials Semiannual Progress Report for Period Ending June 30, 1997, DOE/ER-0313/22, U.S. Department of Energy (1997) p. 61.

2. M.L. Grossbeck, and H.K. Birnbaum, "Low Temperature Hydrogen Embrittlement of Niobium II – Microscopic Observations," Acta Met. 25 (1977) 135.

3. J.F. King, M.L. Grossbeck, G.M. Goodwin, and D.J. Alexander, "Recent Progress on Gas Tungsten Arc Welding of Vanadium Alloys," Fusion Materials Semiannual Progress Report for Period Ending December 31, 1996, DOE/ER-0313/21, U.S. Department of Energy (1996) p. 57.