RECENT PROGRESS ON 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 develop techniques for joining structural components of these alloys.

SUMMARY

Emphasis has been placed on welding 6.4 mm plate, primarily by gas tungsten arc (GTA) welding. The weld properties were tested using blunt notch Charpy testing to determine the ductile to brittle transition temperature (DBTT). Erratic results were attributed to hydrogen and oxygen contamination of the welds. An improved gas clean-up system was installed on the welding glove box and the resulting high purity welds had Charpy impact properties similar to those of electron beam welds with similar grain size. A post-weld heat treatment (PWHT) of 950°C for two hours did not improve the properties of the weld in cases where low concentrations of impurities were attained. Further improvements in the gas clean-up system are needed to control hydrogen contamination.

INTRODUCTION

The susceptibility of vanadium alloys to interstitial embrittlement raises concerns with welding large fusion system components, and the selection of welding methods will have a strong economic impact on component fabrication. The gas tungsten arc (GTA) and electron beam (EB) welding processes are being evaluated in V-4Cr-4Ti with particular emphasis on interstitial contamination.

EXPERIMENTAL RESULTS AND DISCUSSION

It was shown earlier that electron beam welds can be made with satisfactory properties in 6.4 mm plate of V-4Cr-4Ti. A DBTT on the order of -100°C has been achieved. However the technique does not lend itself for use in welding large components because of the requirement for a large vacuum chamber. Other processes such as GTA will be needed, but contamination by impurities in the inert gas atmosphere is a persistent problem. As a result, most of the recent research has focused on the GTA welding process.

A plate of V-4Cr-4Ti, Wah Chang heat 832665, 6.4 mm in thickness was prepared for welding by machining to form a beveled groove between two plates with a 75° included angle. Multi-pass welds with nine passes using filler metal wire fabricated from the same alloy and heat as the base metal were made using GTA welding. This technique was chosen as the standard for the present series of tests. Following welding, Charpy specimens 25.4 mm in length by 3.3 mm square with a notch depth of 0.66 mm and a root radius of 0.076 mm were cut in the L-T direction with respect to the original plate. The notch was cut such that the crack propagated entirely within weld metal, parallel to the weld direction.

Previously reported results indicated that the DBTT for GTA welds could exceed 200°C, and that a PWHT of 950°C for 2 hours could replace the DBTT to around room temperature. However the results were plagued by occasional lower shelf behavior in cases where specimens tested at lower temperatures exhibited upper shelf behavior. Such erratic results were sufficiently frequent to warrant further investigation. Fractography revealed that the lower shelf fracture was almost entirely by cleavage. Inert gas fusion analysis was used to determine the concentrations of interstitials in the weld and base metal of a random selection of welds.[1] Table 1 presents the results of these analyses. Oxygen concentrations were elevated in several of the welds, as expected. However, hydrogen contamination was indicated in GTA 11, GTA 2, and GTA 3. Hydrogen embrittlement is consistent with the observation of cleavage fracture. However, unpredictable cleavage fractures also occurred in specimens which had been given a PWHT of 950°C for 2 h in vacuum, which should be adequate to remove hydrogen from the specimens. It was therefore concluded that the hydrogen-induced cracks must be present prior to the PWHT, and this was confirmed in the case of GTA 11, which cracked during specimen fabrication. X-ray CAT scans revealed a number of cracks in the as-welded plate.

Table 1. Results of analyses for interstitials in V-4Cr-4Ti welds (Wt. ppm)

Base Metal	Weld Metal	H	O	N	C
	GTA 11	58.5	446	288	
GTA 11		53.5	364	96	
Virgin V-4Cr-4Ti					
Etched		1.2			
Weld Wire			360	109	155
	EBW 11	36.4	327	99	
EBW 11		23.1	323	99	
	GTA 2 (VQ11)	11.2			
	GTA 2 (V909)	10.1			
	GTA 3	20.5			
	GTA 8		410	98	
GTA 8			332	96	
	EB 2	2.8			
	EB 12	7.9			

The elevated hydrogen concentration in GTA 11 could have resulted from an air leak in the glove box since oxygen and nitrogen were also high in this weld. However, this does not explain the elevated concentrations in other welds. The system was leak checked and a small leak repaired. In addition, a purification system was added which consisted of a molecular sieve moisture trap followed by a hot titanium sponge oxygen getter system. Gas was withdrawn from the glove box and recirculated using a sealed bellows pump.

Using the purification system, weld GTA 13 was made in an argon atmosphere of 4 wt. ppm oxygen and 23 wt. ppm water. As shown in Table 2 and Fig. 1, an oxygen concentration of 374 wt. ppm and a nitrogen concentration of 104 wt. ppm were achieved, and the resulting DBTT was at ~57°C, with evidence of erratic fracture behavior. In order to examine further the effect of atmosphere impurities, weld GTA 14 was made with an intentionally contaminated environment containing 14 wt. ppm oxygen and 84 wt. ppm water. These conditions resulted in 352 wt. ppm oxygen, 110 wt. ppm nitrogen, and 21 wt. ppm hydrogen in the fusion zone of the weld. The DBTT was raised slightly to 82°C. Weld GTA 15 was made with higher levels of impurities, 27 wt. ppm oxygen and 260 wt. ppm water, and the weld contained 412 wt. ppm oxygen, 146 wt. ppm nitrogen, and 15 wt. ppm hydrogen. Charpy specimens failed in a brittle mode at ~100°C and the DBTT was raised to ~288°C (Fig. 1).

[1]Analyses were performed by Leco, Inc. of St. Joseph, MI.

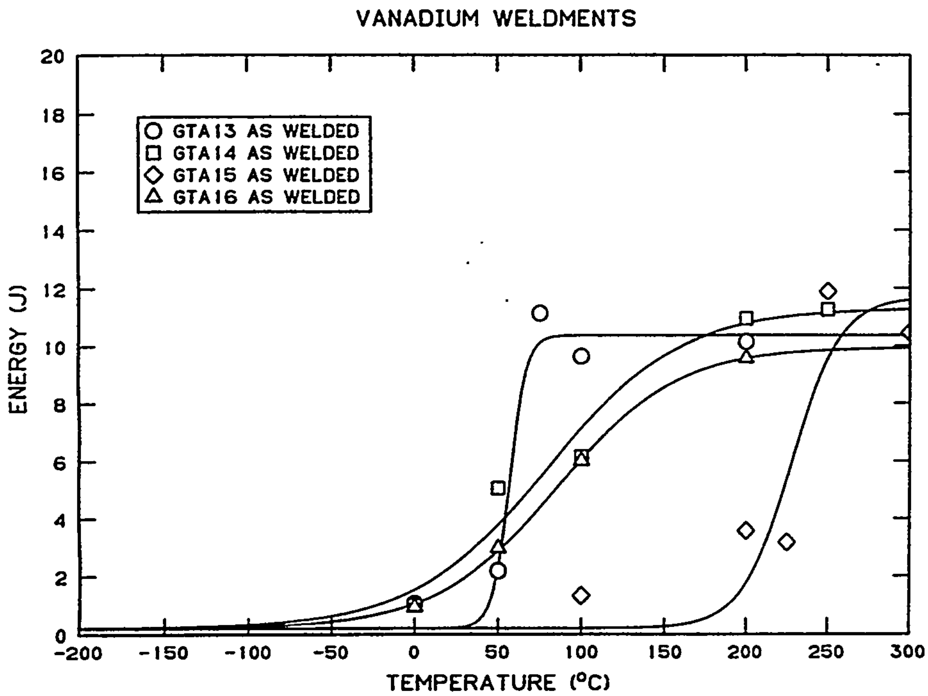

Fig. 1. Charpy impact curves for V-4Cr-4Ti GTA welds in the as welded condition.

A PWHT of 950°C for two hours was applied to all three welds. The results, shown in Fig. 2 and Table 2, demonstrate that little change resulted in GTA 13 and GTA 14, but the high DBTT of GTA 15 was reduced to a level similar to that of the other welds. It appears that the heat treatment, which precipitates oxygen in the form of titanium oxides, improves a contaminated weld, but does little or nothing to an already clean weld, a very significant result considering the difficulty in performing such a high temperature PWHT in the field.

Table 2. Parameters for Impurity Test Series of Welds

		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 13	as welded	4	23	374	104		57
GTA 13	950°C/2h						60
GTA 14	as welded	14	84	352	110	21	82
GTA 14	950°C/2h						80
GTA 15	as welded	27	260	412	146	15	228
GTA 15	950°C/2h						86
GTA 16	as welded	0.8	25	370	107		85
GTA 16	950°C/2h						38

To further confirm the effect of contamination on weld properties, GTA 16 was made with atmospheric impurity levels still lower than those for GTA 13. The impurity concentrations and DBTT values are again shown in Table 2. The welding atmosphere had 0.8 wt. ppm oxygen and 25 wt. ppm water in argon which resulted in an oxygen level of 370 wt. ppm and a nitrogen level of 107 wt. ppm in the fusion zone of the weld. The oxygen level in the base metal was 336 wt. ppm, thus the oxygen level increased during welding by only 10%. In spite of the lower levels of oxygen and moisture in the glove box atmosphere, the DBTT for this weld was

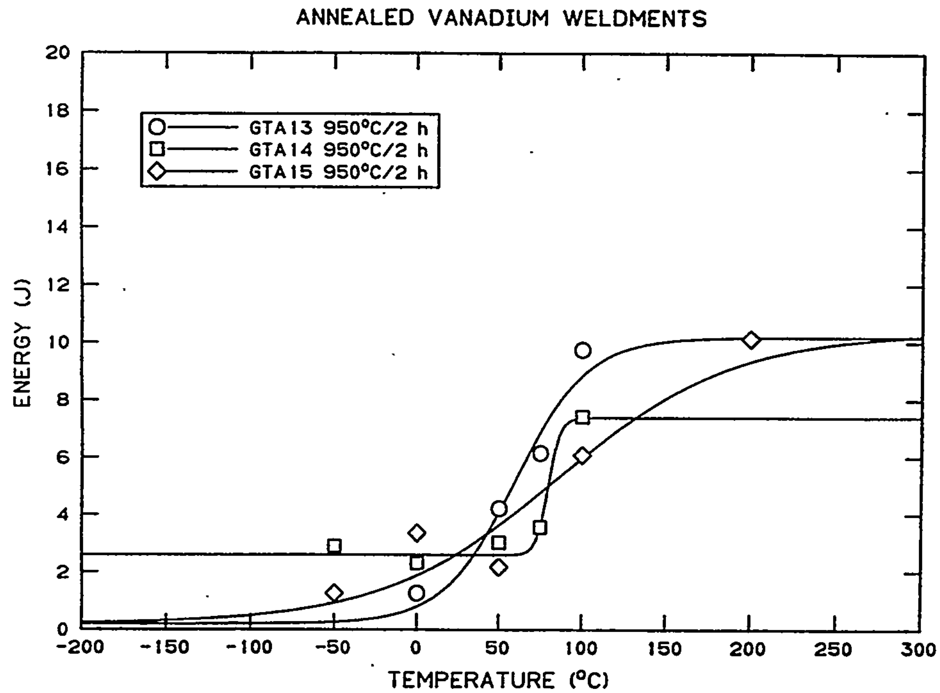

Fig. 2. Charpy impact curves for V-4Cr-4Ti TTA welds following an oxygen precipitation post weld heat treatment of 950°C for two hours.

no better than those for welds GTA 13 and GTA 14. However, the hydrogen concentration in the weld was determined to be unexpectedly high (~63 wt. ppm). An out gassing heat treatment of 400°C for 1 hour was performed and the Charpy tests repeated; the curve shown in Fig. 3 shows an improvement in DBTT to 38°C, but a return of the erratic behavior illustrated by the specimen tested at 100°C, which failed by cleavage. It was concluded that cracking was present prior to the out-gassing treatment at 400°C, indicating that further improvements in the gas purification system are needed.

The titanium sponge in the purification system is held at 600-800°C. At this temperature, water is reduced and oxygen is readily reacted to form titanium oxide, but no hydride of titanium is stable. Hydrogen is, therefore, passed along into the glove box. Clearly the molecular sieve trap is not adequate to remove moisture from the system so that an additional hydrogen trap will be necessary.

These results are significant in that they illustrate that high purity GTA welds can be made and that they may not require a post-weld heat treatment. Further work remains to be done on controlling hydrogen, and grain size refinement remains to be investigated.

CONCLUSIONS

1. Low interstitial content welds can be made by the gas tungsten arc method using a high-purity glove box atmosphere with special purification.

2. A high-temperature post-weld heat treatment for oxygen precipitation may not be necessary if the atmosphere can be made sufficiently pure.

3. Hydrogen is easily incorporated into vanadium alloy welds and can cause cracking.

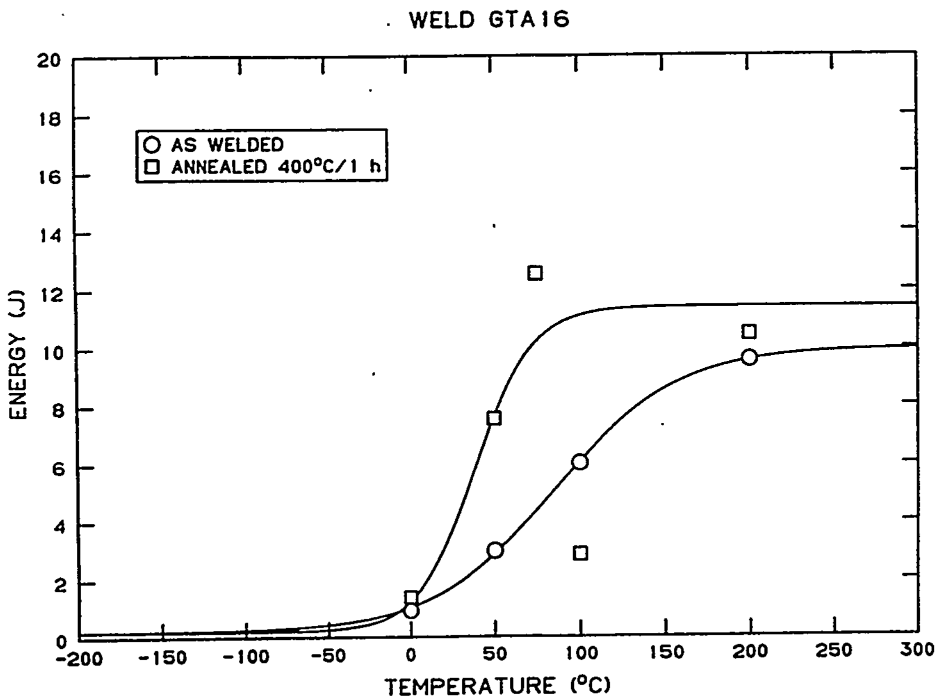

Fig. 3. Charpy impact curves for V-4Cr-4Ti weld GTA 16 in both the as welded condition and following a hydrogen out gassing heat treatment of 400°C for 1 h.