LASER-WELDED V-Cr-Ti ALLOYS: MICROSTRUCTURAL AND MECHANICAL PROPERTIES*

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OBJECTIVE

The objectives of this task are to (a) determine the optimal parameters for laser beam welding of sheets of V-Cr-Ti alloys; (b) examine the microstructural characteristics of welded sections, including base metal, heat-affected-region, and core of weld; (c) evaluate the influence of different postwelding heat treatments on microstructural characteristics; and (d) evaluate the mechanical properties, such as tensile and impact, of laser-welded materials.

SUMMARY

A systematic study has been in progress at Argonne National Laboratory to examine the use of YAG or CO_2 lasers to weld sheet materials of V-Cr-Ti alloys and to characterize the microstructural and mechanical properties of the laser-welded materials. During this report period, thirty eight weldments were made with a YAG laser; the emphasis was on determining the optimal weld parameters to achieve deep penetration in the welds while eliminating porosities found previously[1]. A preliminary assessment was then made of the weldments on the basis of visual appearance and sectioning to determine depth of penetration and extent of porosity.

EXPERIMENTAL PROGRAM

The heat of vanadium alloy selected for the study had a nominal composition of V-4 wt.%Cr-4 wt.%Ti (designated as BL-71). A 4-mm-thick sheet of the alloy was used for the welding study. Earlier microstructural and hardness results were presented in a previous report [1] from welding of a 4-mm-thick plate with a YAG laser in a pulsed mode. The purpose of that study was to increase the weld penetration from ≈1.2 mm in earlier welded samples to as deep as 3 mm or more. Welding parameters such as power, traverse speed, pulse time, overlap, etc., were examined to obtain optimal quality in the final weld. Those welds lacked the full 4 mm penetration desired, and also contained some porosity. During this period, a series of welding tests was conducted, the main purpose of which was to obtain ideal welds which have enough penetration for Charpy impact specimens (weld depth > 2.74 mm) but no root porosity, surface splatter or plate-out. Two different focal length lenses (5" and 3") were tested under different laser parameters and beam travel speeds. To avoid the cracking and oxidation of the welds, high-purity argon (99.999%) was used as the shielding gas with a flow rate of 25 L/s, provided by a 9.5-mm diameter tube at 30° from horizontal. Some tests were also conducted using an environmental control box to improve the quality of the welding atmosphere.

RESULTS AND DISCUSSION

In the last report [1], we presented microstructural and hardness data on laser-welded V-4Cr-4Ti alloy. The welds in that study were made with a YAG laser in the pulsed mode, the energy of the laser beam was 4.5-5.5 J/ms; pulse width was maintained at 3 ms, and workpiece traverse speed was varied between 10 and 40 mm/s. Weld depth in those specimens reached 2.23 mm; still inadequate for Charpy specimens. Root porosity was also found.

During this period, the series of welds listed in Table 1 was completed.

Table 1 Laser Welding of Vanadium

Weld No.	Penetration (mm)	Laser Schedule E-L-R*	Feed (cm/s)	Lens	Focal Position	Porosity? **	Irregular or splatter surface ?	Ideal Welds
1	2.74	4/3/66	1	5"	@ Surface			Y
2	3.15	4/3/66	0.5	5"	@ Surface			Y
3	2.53	4/3/66	1	5"	@ Surface		Y	
4	3.42	4/3/66	0.5	5"	@ Surface			Y
5	2.81	4/3/66	1	5"	@ Surface			Y
6	2.91	4/3/66	1	5"	@ Surface			Y
7	2.38	4/3/66	1.5	5"	@ Surface	Y		
8	2	6/2/66	1.5	5"	@ Surface		Y	
9	1.17	6/2/66	2	5"	@ Surface		Y	
10	1.86	4/3/66	2	5"	@ Surface			
11	2.43	4/3/66	1.5	5"	@ Surface	Y		
12	1.48	4/3/66	2	5"	1/2 mm into			
13	2.53	4/3/66	1.5	5"	@ Surface			
14	2.54	5/2.5/64	1.5	5"	@ Surface	Y		
15	1.94	5/2.5/64	2	5"	@ Surface		Y	
16	1.89	5/2.5/64	2	5"	@ Surface		Y	
17	2.26	4/3/66	1.5	5"	@ Surface			
18	2.02	4/2/100	1.5	5"	1 mm into		Y	
19	2.2	4/3/66	1.5	5"	1 mm into			
20	2.17	4/3/66	1.8	5"	1 mm into	Y		
21	2.16	4/3/66	2	5"	1 mm into	Y		
22	2.82	4/3/66	1.5	3"	1 mm into			Y
23	2.81	4/3/66	2	3"	1 mm into	Y		
24	1.66	4/3/66	4	3"	1 mm into			
25	1.75	4/3/66	3	3"	1 mm into			
37	2.43	5/3/53	2	3"	1 mm into			
38	1.79	5/3/53	3	3"	1 mm into		Y	
39	2.5	5/3/53	2.5	3"	1 mm into	Y		
40	1.92	5.5/3/48	3	3"	1 mm into		Y	
41	2.5	5.5/3/48	2.5	3"	1 mm into	Y	Y	
42	2.37	5.2/3/51	2.5	3"	1 mm into	Y		
43	2.8	5.2/3/51	2	3"	1 mm into	Y		Y
44	2.18	5.2/3/51	3	3"	1 mm into			

* The meanings of the E-L-R in the laser schedule, a control program used to control the firing of the laser are as follows:
E: energy per unit time in joules/millisecond,
L : the pulse width in milliseconds and
R: the repetition rate in Hz or Pulses per second.

The laser schedule can be run under normal mode or alternative mode. In normal mode, the two rods fire the laser at same time, and in alternative mode, they fire alternatively. Alternative mode was used for all the V welds. In alternative mode, the real repetition rate is two times of the R number. For example, Laser Schedule E4L0.5R100 (ALT), gives energy per unit time of 4 J/millisecond, pulse width of 0.5 milliseconds, and repetition rate of 2 X 100 = 200 Hz.

* *Porosity was examined at a single, randomly selected cross section via 400X optical microscopy.

The welds were metallurgically analyzed to characterize the weld depths and the microstructures. Root porosity was found in welds produced under relatively high beam travel speeds. Porosity was examined at a single, randomly selected cross section via 400X optical microscopy. Splatters were generated when the peak power of the laser beam was too high. Ideal welds (no porosity or irregular surface, and weld depth>2.74 mm) were achieved for each of the following three conditions:

1) 5" lens, laser schedule E4R3L66, and beam travel speed, F<= 1 cm/s,
2) 3" lens, laser schedule E4L3R66 and beam travel speed, F<= 1.5 cm/s, and
3) 3"lens, laser schedule E5.2L3R51 and beam travel speed, F<= 2 cm/s.

Weld depths of larger than 3 mm without porosity were obtained at beam speeds of 0.5 cm/s for 5" lens, and > 2.8 mm at 1,5 cm/s for 3" lens. The weld depth required by the Charpy impact test specimen is larger than 2.74 mm. The ideal welds produced using 5" lens and 3" lens are shown in Figures 1 and 2.

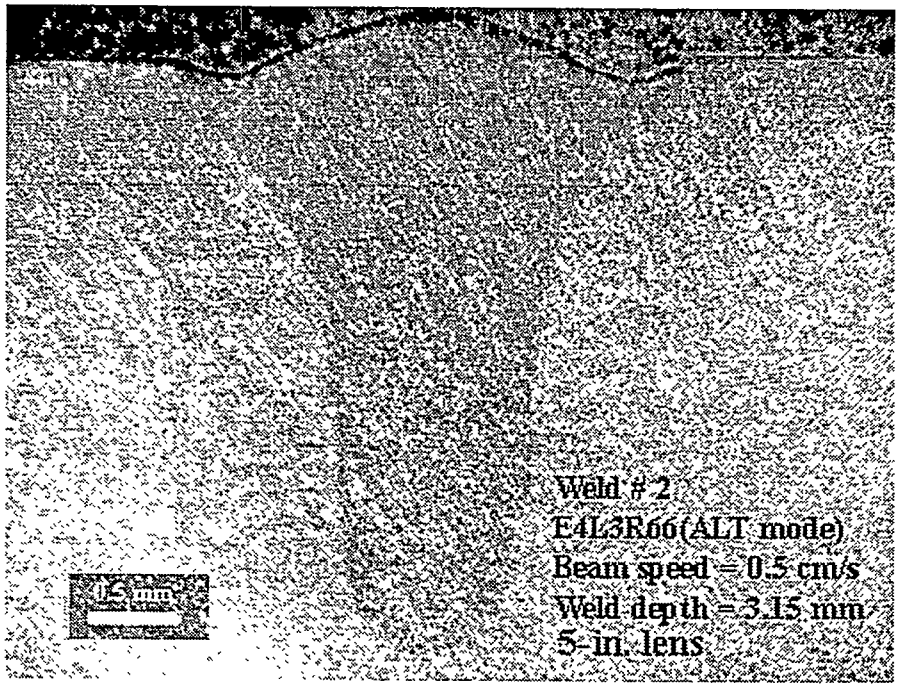

Figure 1 Weld produced under laser schedule of E4L3R66 and beam travel speed of 0.5 cm/s for 5" lens.

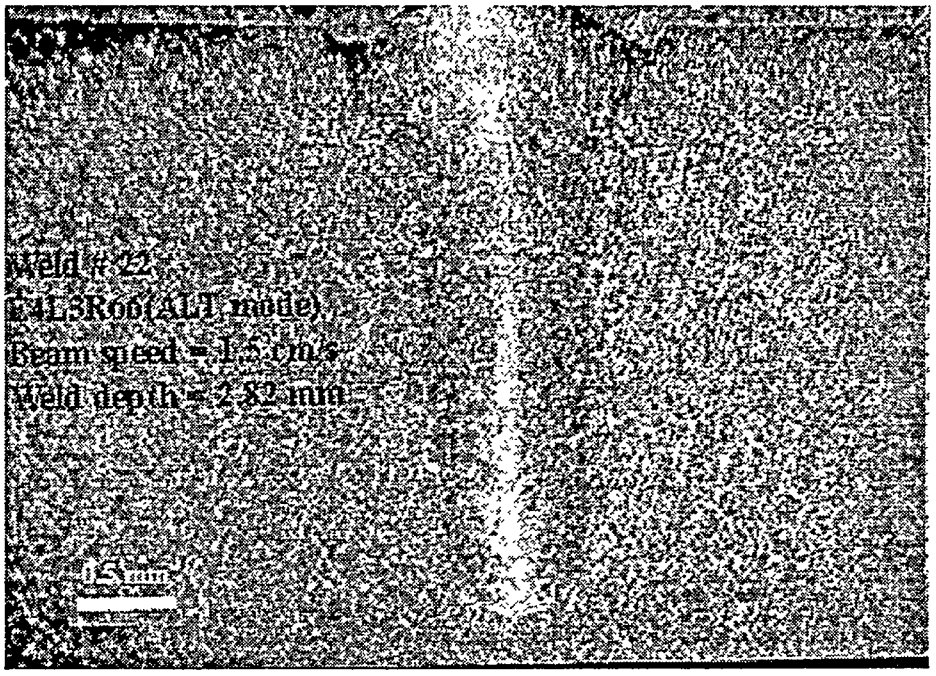

Figure 2 Weld produced under laser schedule of E4L3R66 and beam travel speed of 1.5 cm/s for 3" lens.

In the next report period, the deepest welds achieved so far will be sectioned longitudinally to comprehensively examine for porosity. Sections of weld metal will also be analyzed for oxygen content and correlated with weld hardness.

A welding environment control (containment) box was assembled within the laser system. The gas lines and vacuum ports were tested. The use of the containment box is expected to provide a controlled atmosphere for laser welding of vanadium and protect it from oxidation, splatter and plate-out.

Five preliminary welds were produced with the environmental control box. The laser schedule used was E4L3R66 (ALT). A 3-inch focal length lens was used, which was focussed at 1 mm into the 4-mm thick plate. The environmental gas was 99.996% purified argon. The environmental control box was first evacuated to 20 in. Hg by a vacuum pump, then the argon was allowed to flow into the box at a flow rate of 30 L/s for 10 to 15 seconds before the laser started firing. The beam travel speed was 1 cm/s for all welds except weld No. 4, which was 0.5 cm/s. Both antireflective coated and non-coated windows were tested. The welds are shown in Figure 3. Though a shiny weld (weld No.1 in Fig. 3) was achieved, a vapor was deposited on the window after a single run. This deposit significantly reduced the transmission coefficient of laser beam through the window and a significant amount of energy was absorbed by the window leading to glazing and cracking of the glass. As a result, the weld depth decreased from the beginning to the end of the welds (see Fig. 3). Further work is necessary to effectively utilize the containment box.

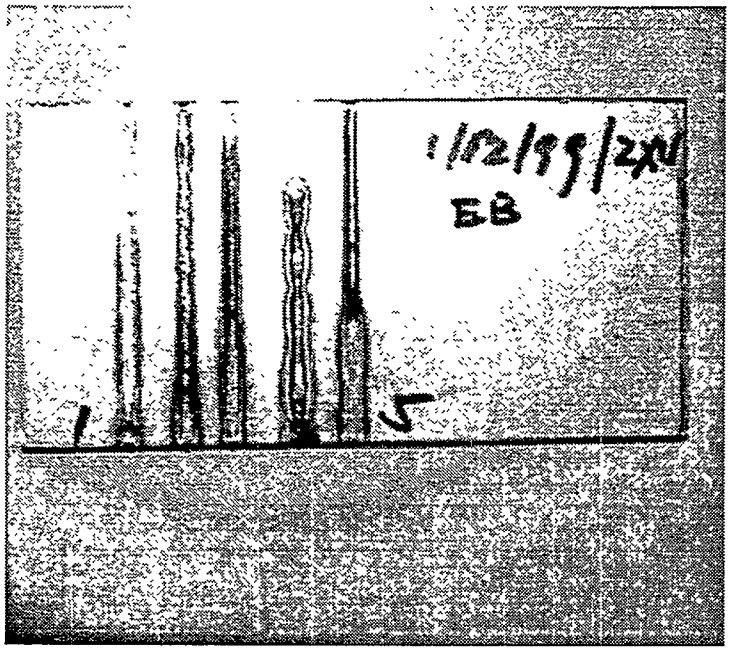

Figure 3 Top view of the welds produced within the environmental control box.

REFERENCES

1. K. Natesan, D. L. Smith, Z. Xu, and K. H. Leong, "Laser-Welded V-Cr-Ti Alloys: Microstructural and Mechanical Properties," Fusion Reactor Materials Progress Report for the Period Ending June 30, 1998, Argonne National Laboratory, DOE/ER-0313/24, p. 87, June 1998.