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. In addition, several postwelding heat treatments are being applied to the welded samples to evaluate their benefits, if any, to the structure and properties of the weldments. Hardness measurements are made across the welded regions of different samples to evaluate differences in the characteristics of various weldments. Several weldments were used to fabricate specimens for four-point bend tests. Several additional weldments were made with a YaG laser; here, the emphasis was on determining the optimal weld parameters to achieve deep penetration in the welds. A preliminary assessment was then made of the weldments on the basis of microstructure, hardness profiles, and defects.

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 reported on several different welds made under the same welding conditions but subsequently given different postwelding heat treatments [1]. Several of these weldments were fabricated into four-point bend specimens with a cross section of 3.3 mm and a shallow notch in the base-metal side of the welded specimen. Testing of these specimens at several temperatures (such as that of liquid N_2, -100°C, -40°C, and room temperature) is in progress. During this period, welding of an additional 4-mm-thick plate was continued with a YaG laser in a pulsed mode. The purpose of this study is 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., are being examined to obtain optimal quality in the final weld. Samples are being cut from different welds, and detailed microstructural analysis and hardness measurements are being conducted.

RESULTS AND DISCUSSION

In the last report, 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 a continuous mode of operation and with an spatial overlap of 90-95%. Weld depth in those specimens was ≈1.2 mm and the hardness profiles showed a substantial increase (from an initial Vickers hardness value of 170-180, upto 240-280) in the center of the weld; this value stayed high across almost the entire weld zone. The earlier effort directed at developing an acceptable postwelding heat treatment showed that five passes of diffused laser beam over the welded region softened the weld material, especially in the root region of the weld. Several of these post-welded materials have been used to fabricate four-point bend specimens and testing of these specimens, at room temperature has begun.

During this period, YaG laser welding of additional 4-mm-thick plate was continued in the pulsed mode. The purpose of this study is to increase the weld penetration from ≈1.2 mm in earlier-welded samples to as deep as 3 mm or more. In the pulsed mode, the energy of the laser beam was increased to values of 4.5-5.5 J/ms; pulse width was maintained at 3 ms. Further, workpiece traverse speed was varied between 10 and 40 mm/s.

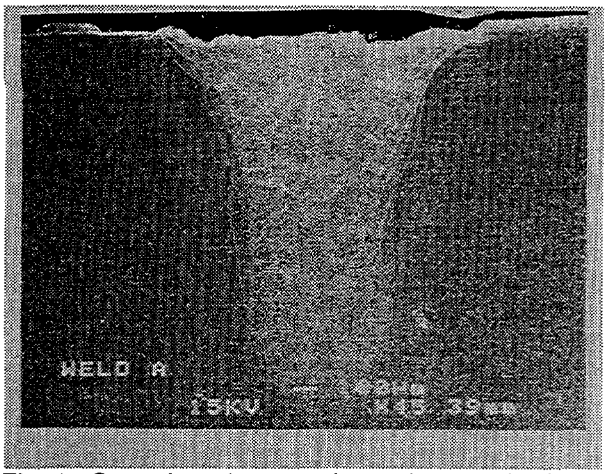

Fig. 1. Scanning electron photomicrograph of weldment A.

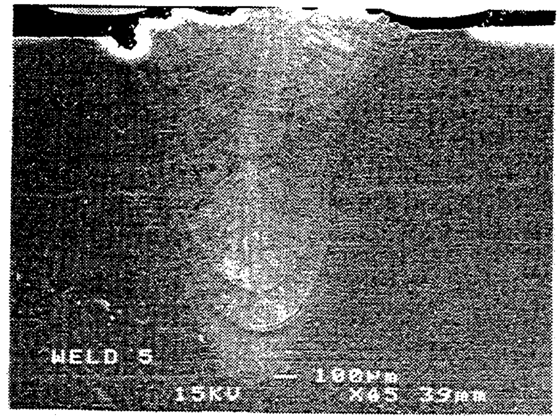

Fig. 2. Scanning electron photomicrograph of weldment 5.

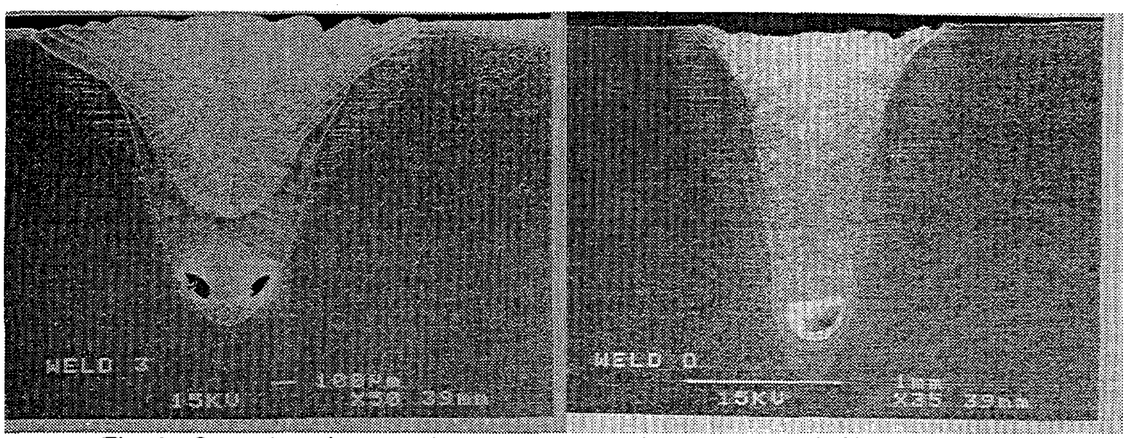

Fig. 3. Scanning electron photomicrograph of weldments 3 (left) and D (right).

Four different welds (identified as A, B, C, and D) were made with laser energy in the range of 5.2-5.5 J/ms. The work piece traversed at 30, 20, 25, and 25 mm/s for welds A, B, C, and D, respectively. Penetration depths in the four welds were 1.80, 2.46, 2.23, and 2.23 mm, respectively. Weld A, with a shallower penetration, exhibited almost no porosity, and no undue material transfer to the weld surface was noted. Figure 1 shows a low-magnification photomicrograph of weld A. Welds B, C, and D, with somewhat deeper penetration, exhibited root porosity in the weld as shown in Figure 2 for weld D, which is typical of the others. The cause of this root porosity and the adjustments to welding parameters in order to eliminate this defect are under investigation.

Six different welds (identified as 1, 2, 3, 4, 5, and 6) were made with laser energy of 4.2 J/ms; pulse width was maintained at 3 ms. The workpiece traverse speed was maintained at 40 mm/s for welds 1, 2, and 3, while for welds 4, 5, and 6 it was 30 mm/s. Depths of penetration in the six welds were 1,26, 1.37, 1.26, 1.65, 1.78, and 1.59 mm, respectively. Examination of the weld cross sections showed that 4, 5, and 6 had almost no macroporosity, but 1, 2, and 3 exhibited significant root porosity. Figure 3 shows low-magnification photomicrographs of weld 3 (typical of 1, 2, and 3) and weld 5 (typical of 4, 5, and 6). Two conclusions can be drawn from this study. First, to increase the depth of penetration of the weld, the laser energy must be higher; it is evident that the higher energy used for welds A-D resulted in deeper penetration than the lower power used for welds 1-6. Second, the traverse speed of the workpiece seems to have an effect (which may not display a 1:1 correlation) on development of root porosity in the welds. For example, welds 1-3 (made with a traverse speed of 40 mm/s) showed defects, while welds 4-6 (with a traverse speed of 30 mm/s) exhibited no defects. On the other hand, weld A (made with a laser energy of 5.2 J/ms and traverse speed of 30 mm/s) was defect-free, while welds B and C, (made with the same laser energy and traverse speeds of 20 and 25 mm/s) exhibited defects.

In all the welds (1-6 and A-D) made in the present batch, variation in grain size from the root of the weld to the free-surface region was lower than that observed in welds reported earlier [1]. Also, in the earlier welds, the grains near the top of the weld were columnar, which is dictated by rate of cooling and solidification, but such a structure was confined to only the center region in the present welds. Further, the weld cross section shows definite contours evenly spaced in the root region, similar to those observed in earlier welds. The dark- and light-shaded grains in the weld are due to differences in grain orientation, and virtually no compositional variations were observed between these grains.

Vickers hardness measurements were made on defectless weldments in the surface-to-root direction and from the centerline of the weld toward the base metal at half-width of the weld. Measurements were on welds A, 4, 5, and 6. Figure 4 shows the hardness profiles for these welds in the two directions. The results indicate that in three of the four (specimens A, 4, and 6) weldments, the hardness value gradually decreases from ≈200-210 in the centerline of the weld to ≈160 in the base metal over a distance of 0.4-0.5 mm from the weld centerline. In these three weldments, hardness was fairly constant in the range of 200-210 from the surface-to-root direction, after which a sharp drop in hardness is noted. Weldment 5 exhibited unusually high hardness in both directions, the cause for which is not known at present. The results also indicate that substantial additional work is needed to evaluate the role of different weld parameters on the structure and property of the laser weldments.

REFERENCES

1. K. Natesan, D. L. Smith, P. G. Sanders, and K. H. Leong, "Laser-Welded V-Cr-Ti Alloys: Microstructural and Mechanical Properties," Fusion Reactor Materials Progress Report for the Period Ending December 31, 1997, Argonne National Laboratory, DOE/ER-0313/23, p. 136, March 1998.

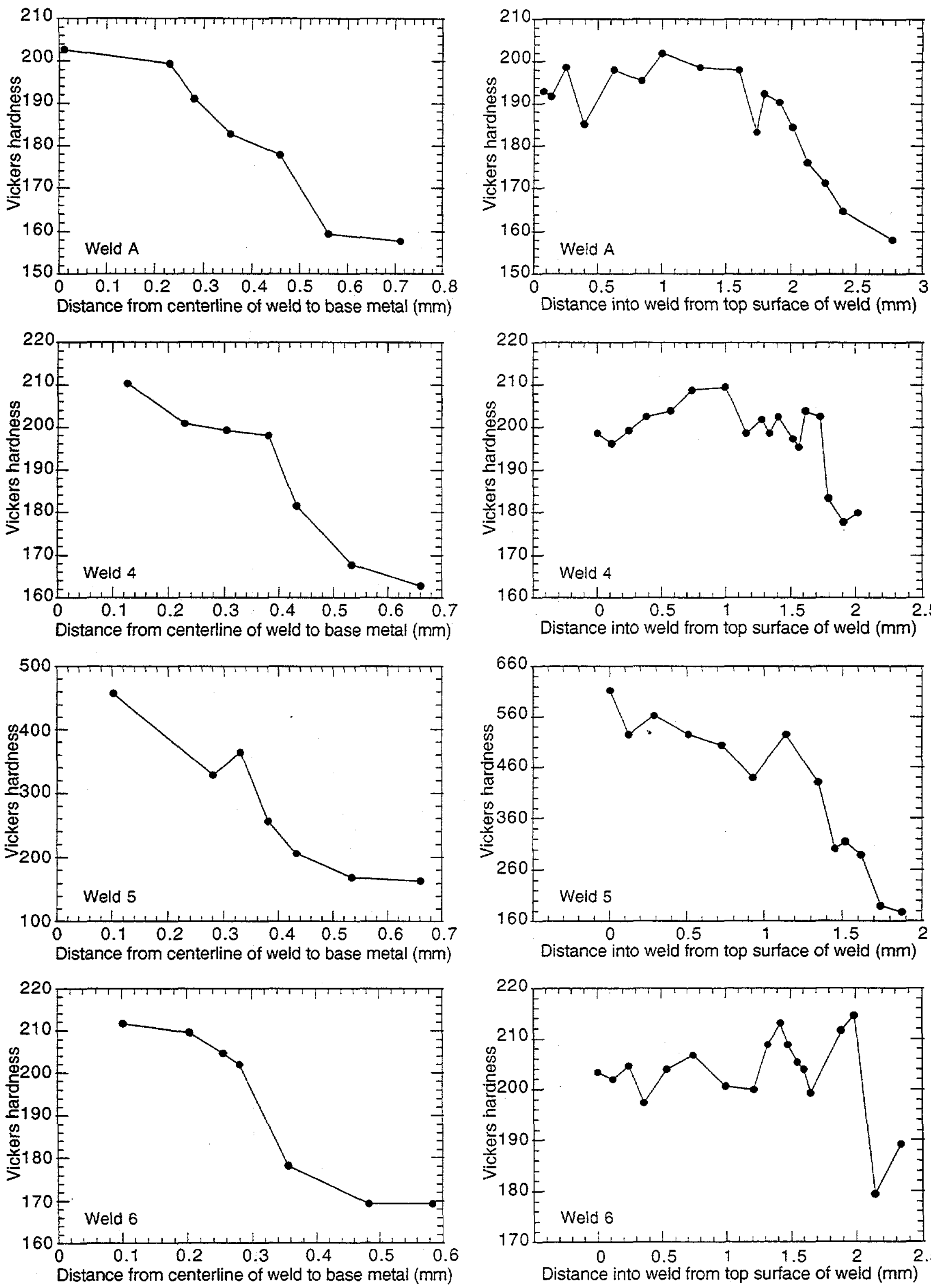

Fig. 4. Vickers hardness profiles for weldments A, 4, 5, and 6 in surface-to-root direction and from weld centerline-to-base metal at half-width of weldment.