IMPACT PROPERTIES AND HARDENING BEHAVIOR OF LASER AND ELECTRON–BEAM WELDS OF V–4Cr–4Ti*

H. M. Chung, R. V. Strain, H.–C. Tsai, J.-H. Park, and D. L. Smith
(Argonne National Laboratory)

SUMMARY

We are conducting a program to develop an optimal laser welding procedure that can be applied to large–scale fusion–reactor structural components to be fabricated from vanadium–base alloys. Results of initial investigation of mechanical properties and hardening behavior of laser and electron–beam (EB) welds of the production–scale heat of V–4Cr–4Ti (500–kg Heat #832665) in as–welded and postwelding heat–treated (PWHT) conditions are presented in this paper. The laser weld was produced in air using a 6-kW continuous CO_2 laser at a welding speed of ≈45 mm/s. Microhardness of the laser welds was somewhat higher than that of the base metal, which was annealed at a nominal temperature of ≈1050°C for 2 h in the factory. In spite of the moderate hardening, ductile–brittle transition temperatures (DBTTs) of the initial laser (≈80°C) and EB (≈30°C) welds were significantly higher than that of the base metal (≈-170°C). However, excellent impact properties, with DBTT < –80°C and similar to those of the base metal, could be restored in both the laser and EB welds by postwelding annealing at 1000°C for 1 h in vacuum.

INTRODUCTION

Recent research in vanadium alloys has focused on development of welding procedures and investigation of the weld properties of the reference alloy V–4Cr–4Ti. A program is being conducted in this laboratory to develop an optimal laser welding procedure that can be applied to welding of large–scale fusion–reactor structural components. An initial bead-on-plate laser weld was produced on 3.8–mm–thick plates of the production–scale heat of V–4Cr–4Ti (500–kg Heat #832665).[1] The base plates were annealed in the factory at a nominal temperature of ≈1050°C for 2 h. To complement the investigation on the structure and properties of the laser weld, EB welds were also obtained from a separate program. In the program, a large–scale MHD test loop was fabricated from the same heat of V–4Cr–4Ti, and a few EB welds were produced as part of the fabrication effort. In this paper, we report results of initial investigation of mechanical properties and hardening behavior of the laser and EB welds of the production–scale heat of V--4Cr–4Ti in as–welded condition and after postwelding heat–treatment (PWHT) at ≈1000°C for 1 h in high vacuum.

MATERIALS AND PROCEDURES

The bead–on–plate laser weld was produced in air with an argon gas purge using a 6–kW continuous CO_2 laser at a welding speed of ≈45 mm/s. Details of the welding procedure are reported in Ref. 1. One-third-size Charpy impact specimens (3.3 x 3.3 x 25.4 mm, 30° notch angle, and 0.61-mm notch depth) were machined from the welded plate. The orientation of the Charpy specimens (L–S orientation) is shown schematically in Fig. 1. Direction of crack propagation was perpendicular to the rolling direction and the flat surface of the plate. As shown, a V–notch was located in the center of the weld zone so that the crack would propagate entirely within the weld zone.

The machined Charpy specimens were subjected to the customary degassing treatment at 400°C for 1 h in ion–pumped vacuum to expel hydrogen. This state of the material is referred to as the "as–welded" condition. Some of the machined specimens were annealed instead at 1000°C for 1 h in ion–pumped vacuum, resulting in the "postwelding heat–treated" (PWHT) condition. Following impact testing at –100 to +300°C, fractographic analysis and microhardness measurement were conducted on broken or bent pieces of the Charpy specimen. Vickers microhardness was measured with a 25-g load near the fracture region on one side of the Charpy specimen. Results of microstructural and microchemical analyses aimed at mechanistic understanding of the fracture behavior are given Ref. 2.

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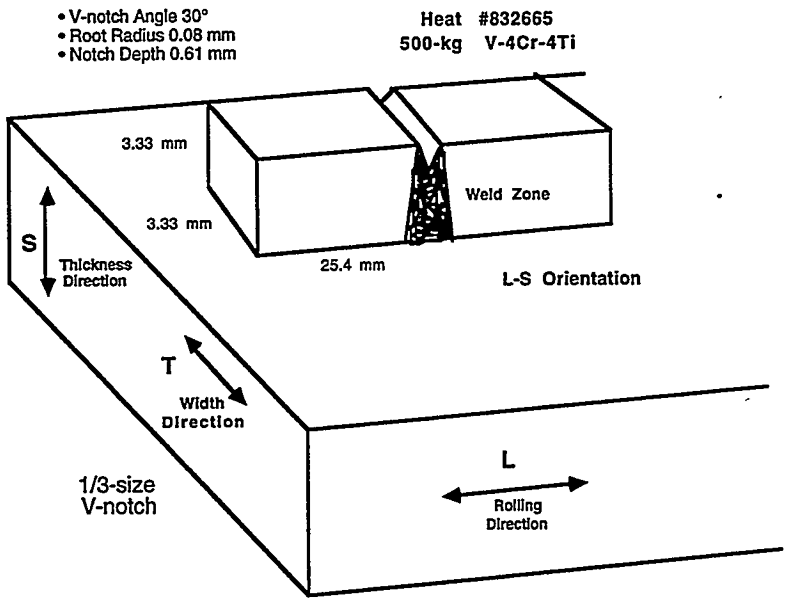

Fig. 1. Orientation of Charpy-impact specimens of laser and EB welds of V-4Cr–4Ti

RESULTS AND DISCUSSION

Impact properties of the laser and EB welds measured at –100 to 300°C are shown in Figs. 2 and 3, respectively. In the figures, weld impact energies measured after degassing the machined Charpy specimens at 400°C (as–welded condition) and at 1000°C (PWHT condition) are shown for comparison. Impact energy of the base metal is also plotted in Fig. 2 as a function of temperature. The DBTTs of the laser and EB welds were ≈80°C and ≈30°C, respectively. These are significantly higher than the DBTT of the base metal (≈–170°C). However, excellent impact properties with DBTTs <–80°C could be restored in both the laser and EB welds by postwelding annealing at 1000°C for 1 h. Impact energies at <–80°C could not be measured because a sufficient number of specimens were not available. True DBTTs of the postwelding annealed laser and EB welds are probably as low as, or lower than, the DBTT of the base metal. However, this must be verified by further testing at <–80°C.

Consistent with the effects of PWHT on impact properties, the microhardnesses of the laser and EB welds decreased significantly after postwelding annealing. This is shown in Figs. 4 and 5, respectively. Vickers hardnesses of the fusion zones of the laser and EB welds were ≈200 and ≈170, respectively, in as–welded condition. After the postwelding annealing, hardness decreased to ≈130. Hardness of the base metal decreased from ≈160 to ≈130 after the postwelding annealing.

As expected, impact properties of the laser and EB welds seems to be more sensitive to postwelding annealing at 1000°C than hardening behavior. Apparently, a similar type of metallurgical process seems to occur during the postwelding annealing of laser and EB welds. Identifying this process is therefore important in gaining an understanding of the mechanism causing the drastic improvement in impact toughness that is associated with the postwelding annealing.

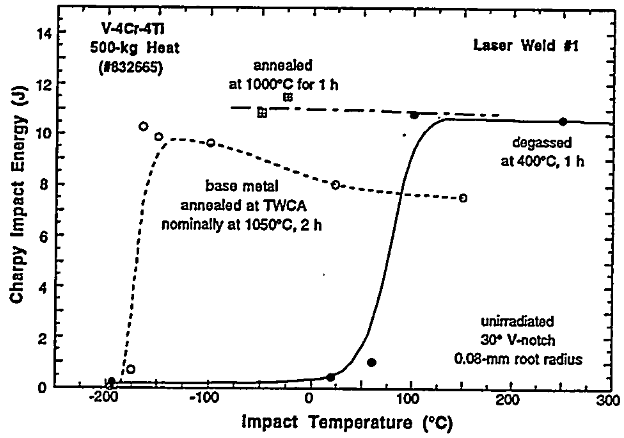

Fig. 2.

Impact properties of base metal and laser weld of V–4Cr–4Ti after annealing under various conditions.

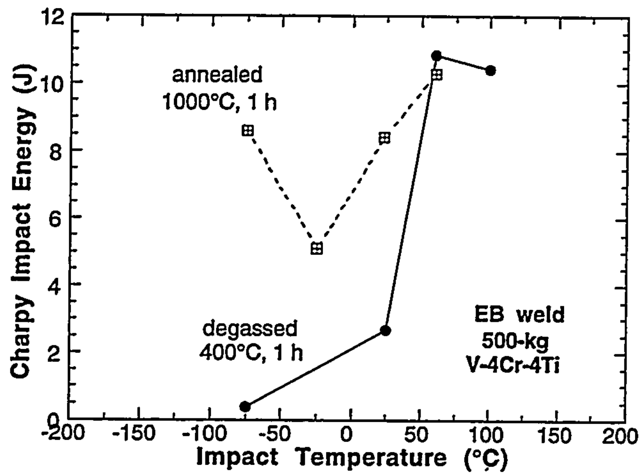

Fig. 3.

Impact properties of electron–beam weld of V–4Cr–4Ti after annealing at 400 and 1000°C.

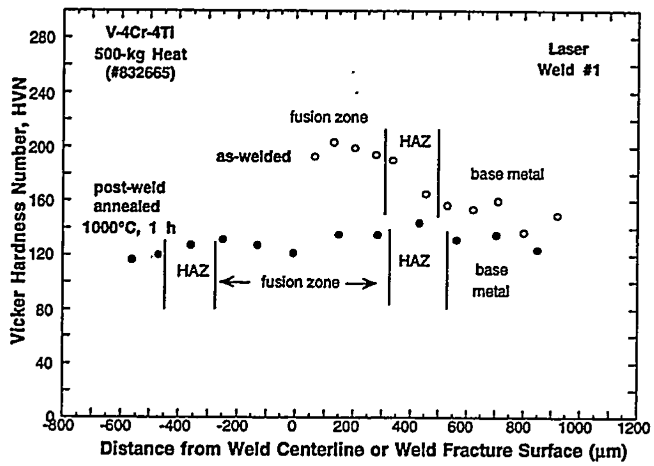

Fig. 4.

Hardness of laser weld of V-4Cr-4Ti before and after annealing at 400 and 1000°C.

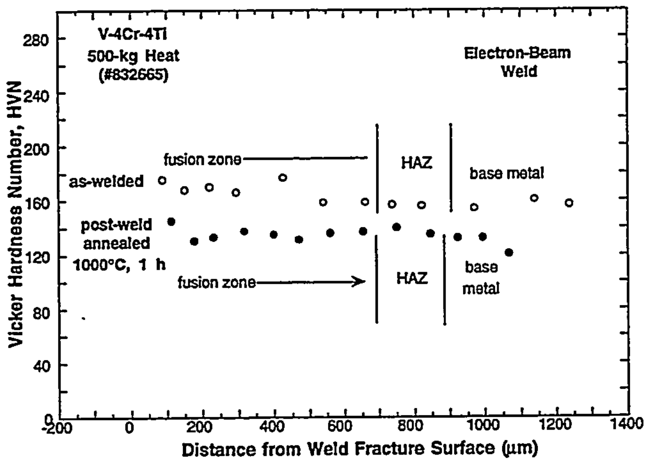

Fig. 5.

Hardness of electron–beam weld of V-4Cr–4Ti after annealing at 400 and 1000°C.

CONCLUSIONS

1. Hardening behavior and impact properties of laser and electron–beam (EB) welds of V–4Cr–4Ti were investigated with and without postwelding annealing at 1000°C for 1 h in high vacuum. Ductile–brittle transition temperatures (DBTTs) of the laser and EB welds were ≈80°C and EB ≈30°C, respectively, significantly higher than the DBTT of the base metal. However, excellent impact properties could be restored in both the laser and EB welds by postwelding annealing at 1000°C for 1 h in vacuum.

2. Consistent with the effect on impact properties, microhardness of the laser and EB welds decreased significantly following postwelding annealing.

3. Impact properties seem to be more sensitive than hardening behavior to postwelding annealing at 1000°C. Apparently, a similar type of metallurgical process seems to occur during the postwelding annealing of laser and EB welds. Identifying this process is therefore important in gaining an understanding of the mechanism that drastically improves impact toughness, as well as in developing an innovative procedure to produce high–quality welds.

REFERENCES

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