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Fundamental Research of 100 kW Fiber Laser Welding Technology

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Abstract

Recently 100 kW fiber laser is commercially available, and so the development of welding technology with 100 kW fiber laser is mostly expected for the utilization of a high power laser. First a focusing optic, a welding nozzle and a power meter were designed and manufactured for such a high power laser, and laser welding was performed under various conditions. The penetrations of laser weld beads were investigated and welding phenomena were observed. Consequently deeply penetrated laser weld beads of more than 40 mm in depth could be produced at 100 kW and 2 m/min, and a sound full-penetration weld bead could be made in a stainless steel plate of 70 mm in thickness with two passes from both surface sides. Moreover, it was confirmed that laser weld beads of about 100 mm to 125 mm in depth were formed under the welding conditions of the high laser power of 50 to 70 kW, the low speed of 0.3 m/min and the low vacuum of 1 kPa.

Keywords: Fiber laser, laser welding, 100 kW laser power, laser welding in vacuum, penetration depth, porosity

1. Introduction

There are some requirements for welding and cutting of thick plates in Japan, and many sets of 10 to 30 kW fiber laser and one set of 100 kW fiber laser have been installed in research institutes, job-shops, steel industries, heavy industries, etc.

In order to obtain a fundamental knowledge of high power laser welding and to develop the welding technology, a focusing optic, a welding nozzle and a power meter were designed and manufactured for 100 kW fiber laser, and welding was performed under various conditions to understand the characteristics of high power laser welding by observing the cross-sectional geometry and penetration depths of weld beads and the welding phenomena. Moreover, high power welding was carried out in low vacuum to obtain a deeply penetrated weld bead.

2. Experimental Procedures

The laser used for welding is 100 kW fiber laser, which is shown in **Fig. 1**. The size is compact. The beam is delivered through an optical fiber of 0.5 mm in diameter and 50 m in length.

The laser head developed is shown in **Fig. 2**. Copper (Cu) mirrors are used for the reduction in thermal lens effect. The focal length is about 1 m. The power meter shown in **Fig. 3** was developed for 100 kW laser. The variation in laser power measured is small, and thus the power seems to be very stable. The traverse mode or power density distribution of a 100 kW fiber laser was measured as a part of laser beam. The mode of a 100 kW laser seems similar to that of normal lasers.

The laser welding was performed as shown **in Fig. 4**. The stage was moved at the given speed.

Fig. 1 100 kW fiber laser apparatus used.

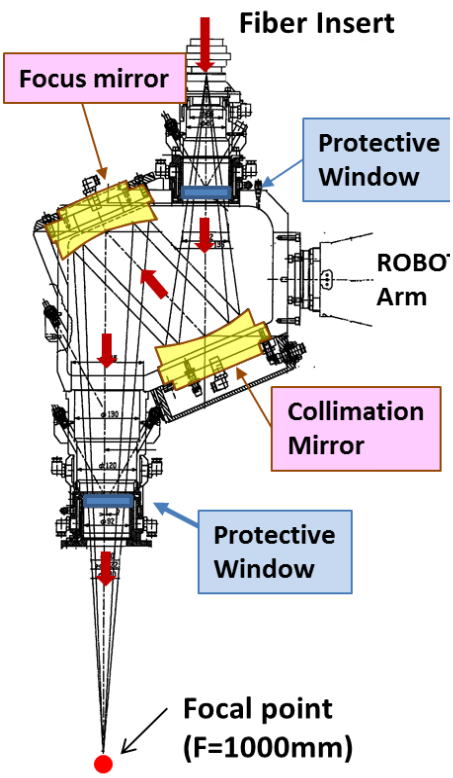


Fig. 2 Focusing optical head developed.

Fig. 3 Power meter developed for 100 kW.

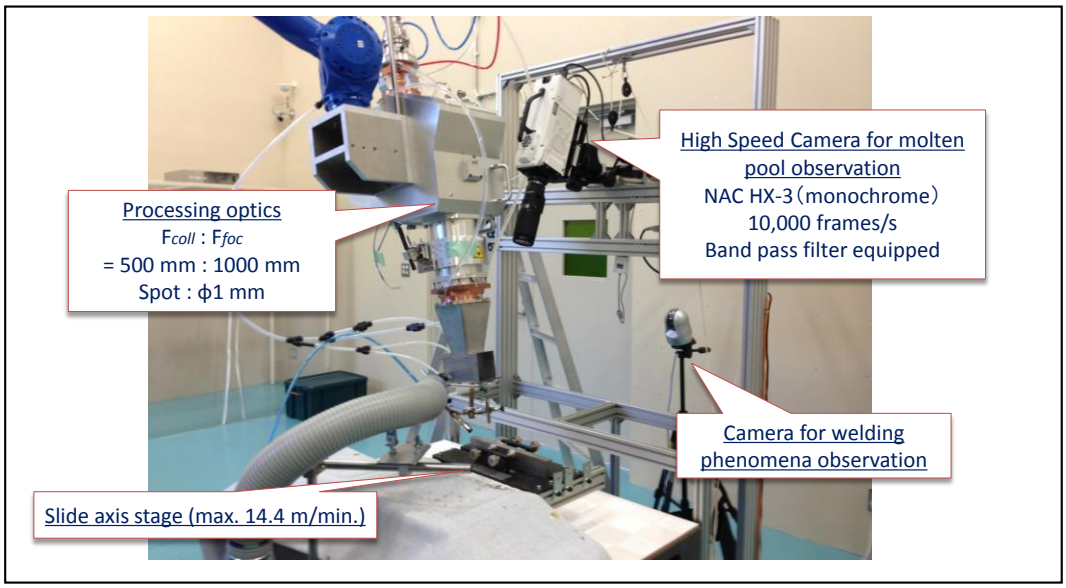


Fig. 4 Setup for laser welding.

3. Experimental Results

3.1 Welding results in shielding gas at 1 atm

The welding of thick plates of Type 304 austenitic stainless steel was performed at different powers and speeds in Nitrogen shielding gas. Examples of cross sections of laser weld beads are shown in **Fig. 5**. At low speeds, porosity and cracks are formed. At 1 m/min and faster, stable sound weld beads are formed. The penetration depths of weld beads are shown at respective laser powers as a function of welding speed in **Fig. 6**. The penetration increases with an increase in the laser power, and decreases with an increase in the welding speed. An example of the surface and cross section of laser weld bead made at 2 m/min is exhibited in **Fig. 7**. A good weld bead of about 40 mm depth is produced, although spatters are severely generated.

Laser welding was performed on an I-butt joint in Type 304 stainless steel plate of 70 mm in thickness at 10 kW and 2 m/min (under the same conditions for the formation of a weld bead in Fig. 7) from both side surfaces to produce a full penetration weld. An example is shown in **Fig. 8**. A sound full-penetration weld bead could be produced in Type 304 stainless steel plate of about 70 mm in thickness.

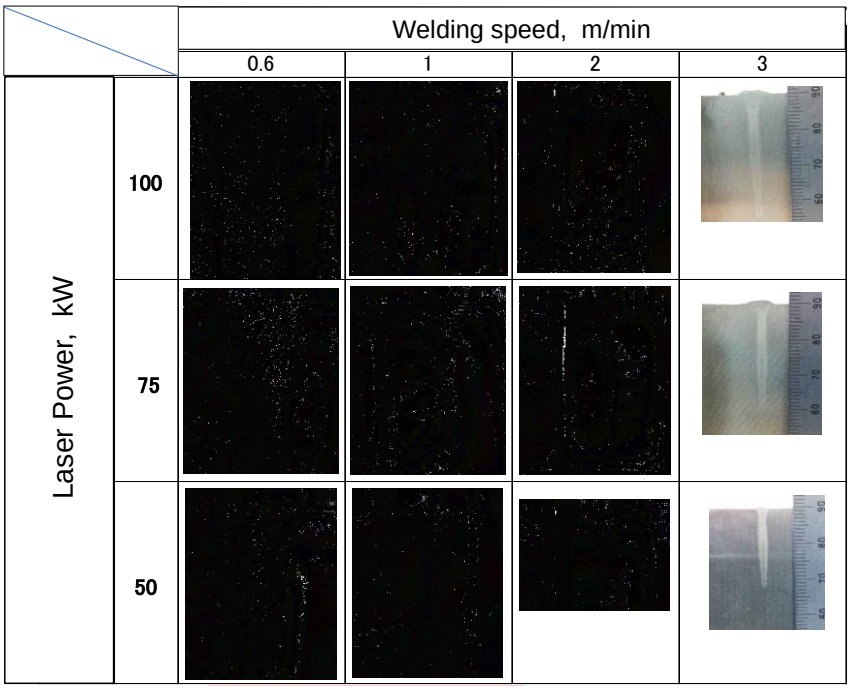


Fig. 5 Cross sections of laser weld beads made at different powers and welding speeds.

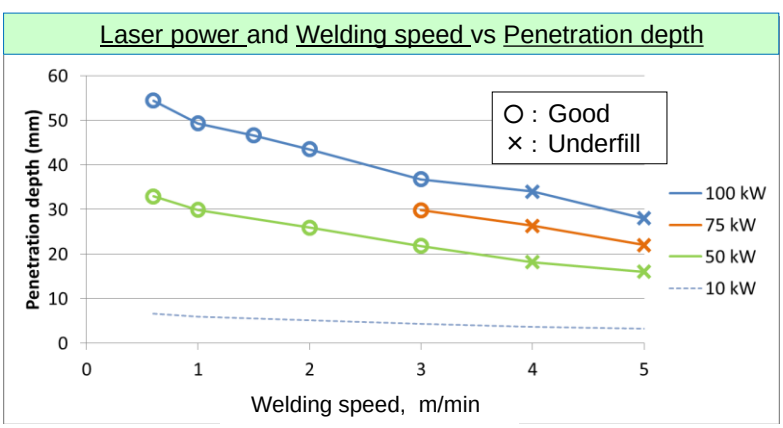
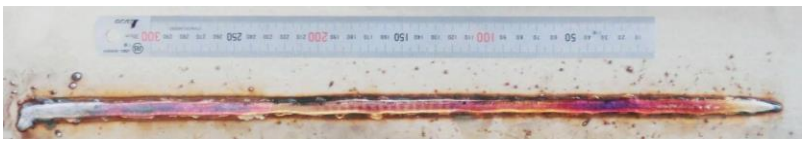
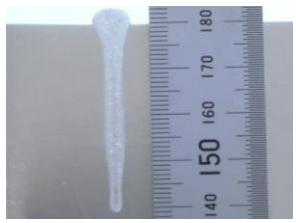


Fig. 6 Effects of laser power and welding speed on penetration depths.



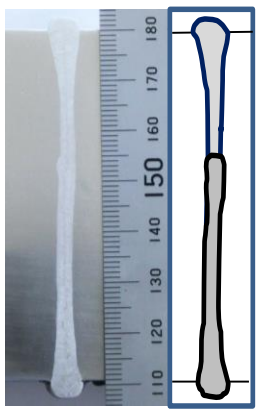
(a) Surface appearance of laser weld bead



(b) Cross section of weld

Fig. 7 Example of laser weld bead made in Type 304 plate at 10 kW and 2 m/min.

(a) Surface appearance of laser weld bead in I-butt joint



(b) Cross section

Fig. 8 Example of laser weld bead made in Type 304 I-butt joint plate of 70 mm in thickness at 10 kW and 2 m/min.

3.2 Welding results in low vacuum

We have developed low vacuum laser welding to produce deep penetration welds [1]. A laser weld bead of about 73 mm in depth was produced at 26 kW (tandem beams of 16 kW and 10 kW), 0.3 m/min and 0.1 kPa. We also evaluate one beam of high power density is superior to two beams in terms of deep penetration [2].

Laser welding was performed at the defocused distance of -30 mm at 0.3 m/min and several powers of 10 to 50 kW in low vacuum by using 100 kW fiber laser. The weld beads made at 0.1 kPa of N_2 gas are shown in **Fig. 9**. It is apparent that the penetration depth of a weld bead increases with an increase in the laser power. Porosity was formed in laser weld beads made at the power of 30 kW and more.

To understand the effect of a vacuum level on porosity formation, laser welding was carried out at 1 kPa. The weld bead made at 30 kW is shown in **Fig. 10**. The porosity was absent under the conditions of 30 kW, 0.3 m/min, -30 mm and 1 kPa. The penetration depth at 1 kPa is given as a function of laser power in **Fig. 11**. 125 mm penetration was obtained at 70 kW, 0.3 m/min, -30 mm, and 0.1 kPa. However, the porosity was present at 40 kW or more. The porosity was reduced at 50 kPa and 5 kPa, as shown in **Fig. 12**. The penetration is slightly shallower, though.

Laser welding was carried out at 50 kW, 0.3 m/min, -30 mm and 1 kPa of Ar gas. A sound weld bead of about 100 in penetration depth was produced.

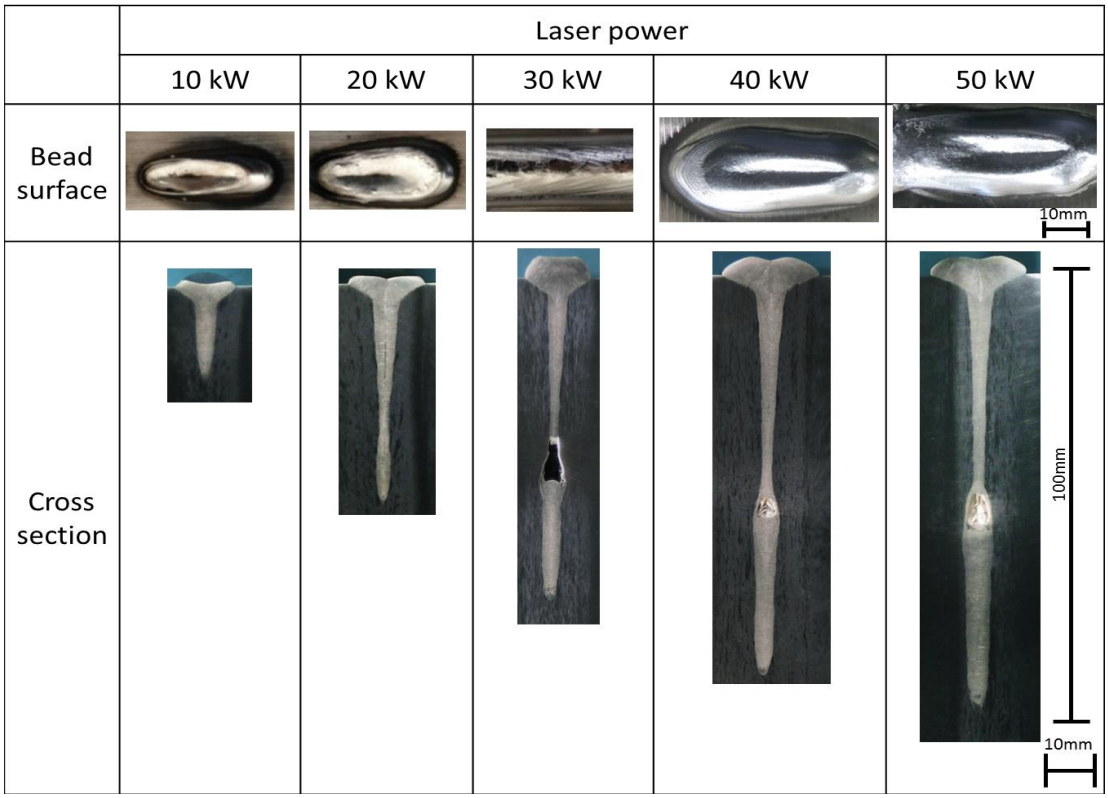


Fig. 9 Surface and cross sections of laser weld beads at 10 to 50 kW in low vacuum of 0.1 kPa, showing porosity at 30 to 50 kW.

(a) Surface of laser weld at 1 kPa (b) Cross section of weld

Fig. 10 Laser weld bead at 30 kW and 0.3 m/min in low vacuum of 1 kPa, showing no porosity.

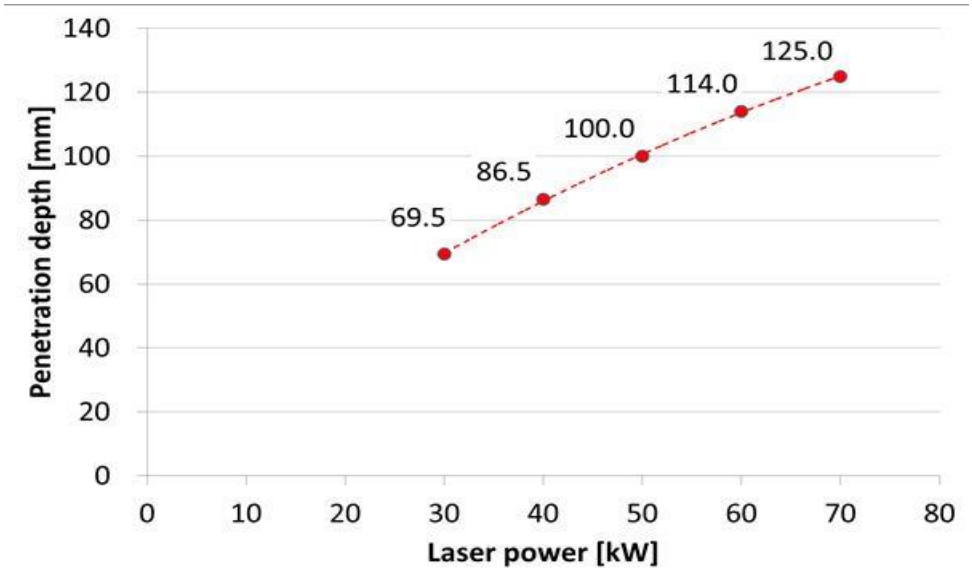


Fig. 11 Effect of laser power on penetration depths of laser weld beads.
Welding speed: 0.3 m/min; Defocused distance: -30 mm; Vacuum: 1 kPa; Used gas: N_2

Fig. 12 Laser weld bead produced at 50 kW, 0.3 m/min, -30 mm and 5 kPa of N2, showing formation of sound weld without porosity.

4. Conclusions

A focusing optic, a welding nozzle and a power meter were manufactured for such a 100 kW power laser, and laser welding was performed under various conditions. Deeply penetrated laser weld beads of more than 40 mm in depth could be produced at 100 kW and 2 m/min, and a sound full-penetration weld bead could be made in a stainless steel plate of 70 mm in thickness with two passes from both surface sides. Moreover, it was confirmed that laser weld beads of about 100 mm to 125 mm in depth were formed under the welding conditions of the high laser power of 50 to 70 kW, the low speed of 0.3 m/min and the low vacuum of 1 kPa.

References

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