# Welding With the High Beam Quality Fiber Laser and Suppression of Welding Defects Using the Beam Mode Control Technology

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**ABSTRACT** The single-mode fiber laser manufactured by Furukawa Electric Co., Ltd. (FEC), with the small core diameter and the high beam quality, is capable of performing a high aspect ratio processing with little thermal influence, at low power by utilizing a high power density. Also the multi-mode fiber laser can reach over 10 mm of penetration depth for steel materials by utilizing its high output power.
However, the commonly used fiber lasers generate many sputters which cause welding defects and defacements around the processing part. To address these issues, we proceeded with the development of the beam mode control technology and succeeded in suppressing sputters and in reducing the processing defects.

## 1. INTRODUCTION

In recent years, the fiber lasers have been receiving a lot of attention, and its replacing of other welding technologies, so far used, has been studied. This is not only because, the fiber lasers have a higher beam quality than the other lasers such as YAG and $CO_2$ which have been conventionally used, but also because the fiber lasers have a high reliability as a device also an excellent energy efficiency and are easy to use.

In this paper, among these lasers, the beam quality of the fiber laser manufactured by FEC and the basic processing performances taking advantage of the device are reported. And, we report the new laser processing which has opened up the possibility through the progress in the beam mode control technology which is gaining attention in recent years.

## 2. THE BEAM QUALITY AND THE PROCESSING PERFORMANCE OF THE FIBER LASER MANUFACTURED BY FEC

The fiber lasers have a high beam quality and a very high light-focusing property, so the weld can penetrates deeply and in addition the thermal influence can be suppressed during the welding. This chapter starts with the introduction of the basic optical properties of the fiber laser manufactured by FEC including a follow-up with the demonstration of the basic processing performance of the multi-mode 6kW fiber laser.

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### 2.1 Beam Quality of the Fiber Laser Manufactured by FEC

The external view of the single-mode fiber laser manufactured by FEC is shown in Figure 1. The inside of the oscillator is composed of a pumping semiconductor laser, gain fiber, Fiber Bragg Grating and other parts, and the oscillated laser light is transmitted to the output end through the optical fiber. Here, the multi-mode fiber laser, shown in Figure 2, combines multiple single-mode fiber lasers to oscillate.


**Figure 1 External view of the single-mode fiber laser.**

The optical specifications of these fiber lasers are shown in Table 1. Compared with the multi-mode fiber laser, the single-mode fiber laser has a smaller fiber core


**Figure 2 External view of the multi-mode fiber laser.**

diameter. Therefore, the penetration with a very high aspect ratio as shown in Figure 3 is available. When an optical system having the same magnification is used, the single-mode fiber laser has a higher power in a per unit area than the multi-mode fiber laser. So, regarding the penetration, as shown in Figure 4, the single-mode laser with 1 kW processing can obtain the equivalent penetration depth of that of the multi-mode fiber laser with 2 kW processing, in a range faster than 20 m/min. On the other hand, in the low speed range where the deeper penetration is required, the multi-mode fiber laser capable of obtaining a high power output is used.

Table 1 Optical specifications of the fiber lasers.

| | Single-mode fiber laser | Multi-mode fiber laser | |
|---|---|---|---|
| Wavelength | 1070 nm | 1070 nm | 1070 nm |
| Rated output | 1500 W | 4000 W | 6000 W |
| Fiber core diameter | 14 μm | 50 μm | 80 μm |
| Beam quality $M^2$ (Typical) | 1.06 | — | — |
| Beam quality BPP (Typical) | — | 2.2 mm mrad | 3.0 mm mrad |

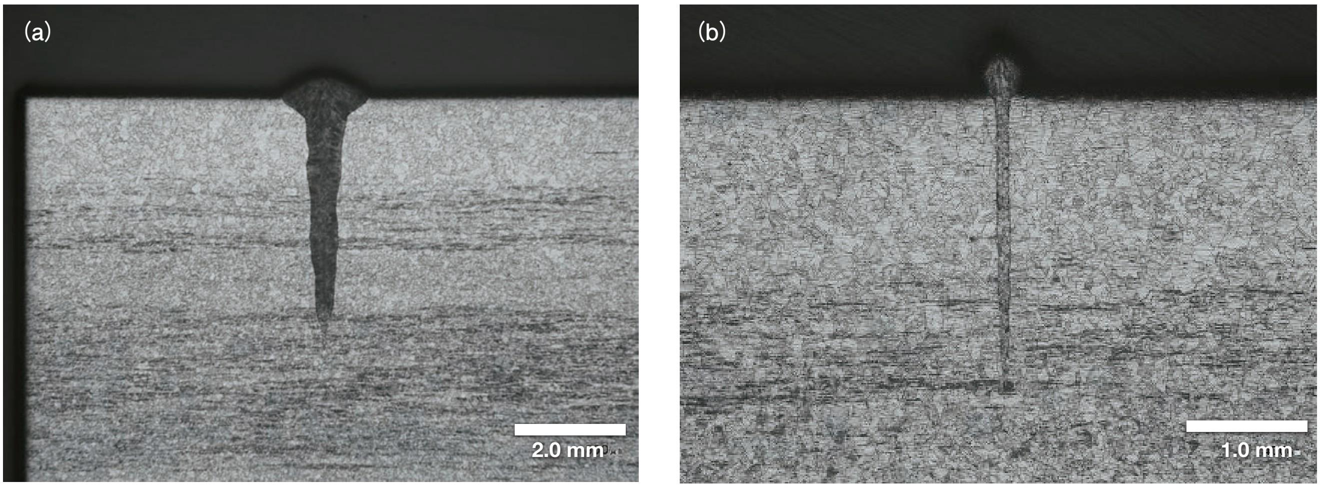


**Figure 3 Cross-sectional view of the steel processed with 1 kW single-mode fiber laser.**
**(a) 1 m/min (b) 10 m/min**

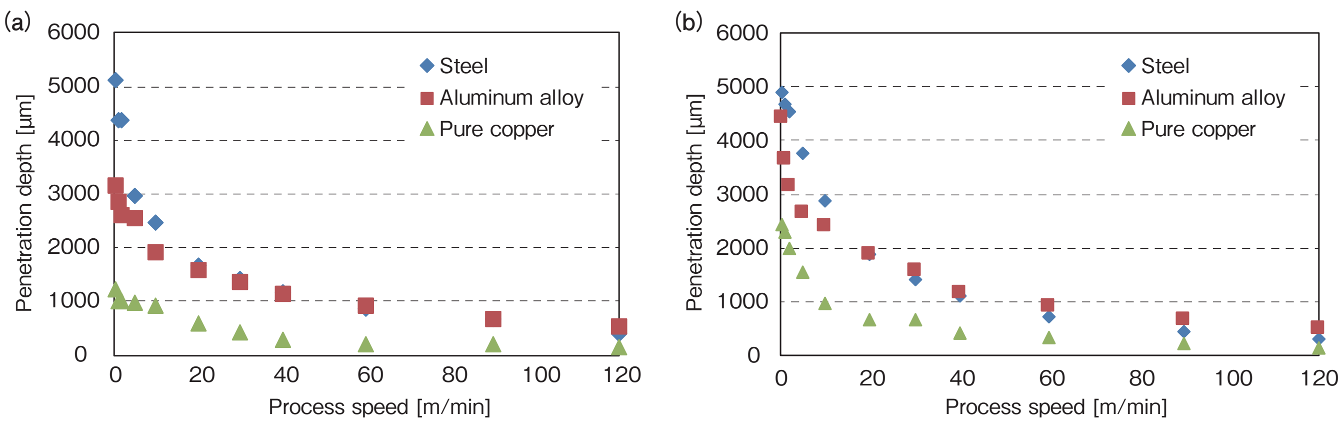


**Figure 4 Comparison of the penetration depths.**
**(a) 1 kW single-mode fiber laser**
**(b) 2 kW multi-mode fiber laser**

### 2.2 Multi-mode Fiber Laser

Using the multi-mode fiber laser, a bead on a plate test was performed on steel, aluminum alloy and pure copper. Figure 5 and Figure 6 show the cross-sectional views on steel and aluminum alloy. By comparing Figure 3 with Figure 5, it is found that although the width of bead is increased, a deep penetration depth is obtained while maintaining the shape of the high aspect ratio. Also, the penetration depth on changing the processing speed is shown in Figure 7. Over 10 mm of the penetration depth can be obtained with stainless steel, steel and aluminum, in low speed range.

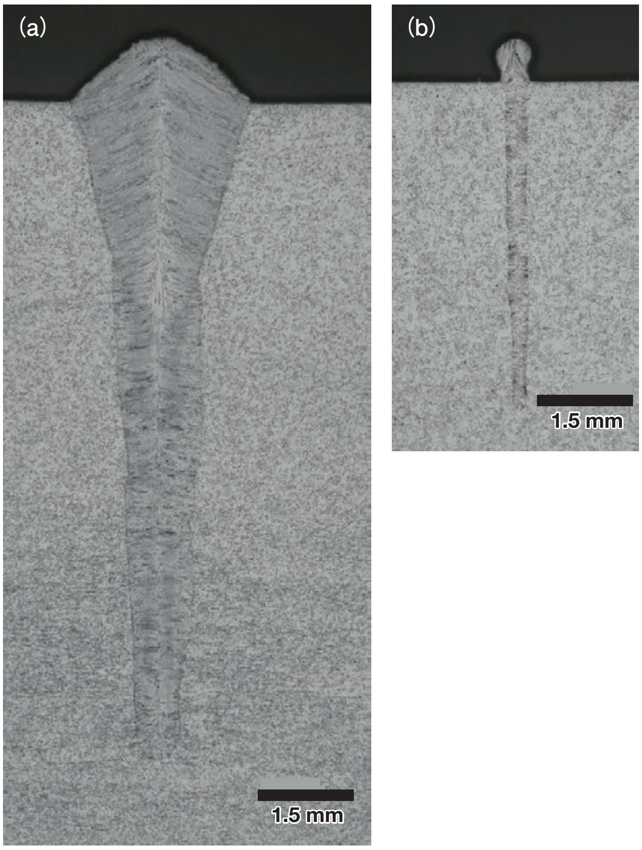


**Figure 5 Cross-sectional view of the steel processed with a 6 kW multi-mode fiber laser.**
**(a) 1 m/min (b) 10 m/min**

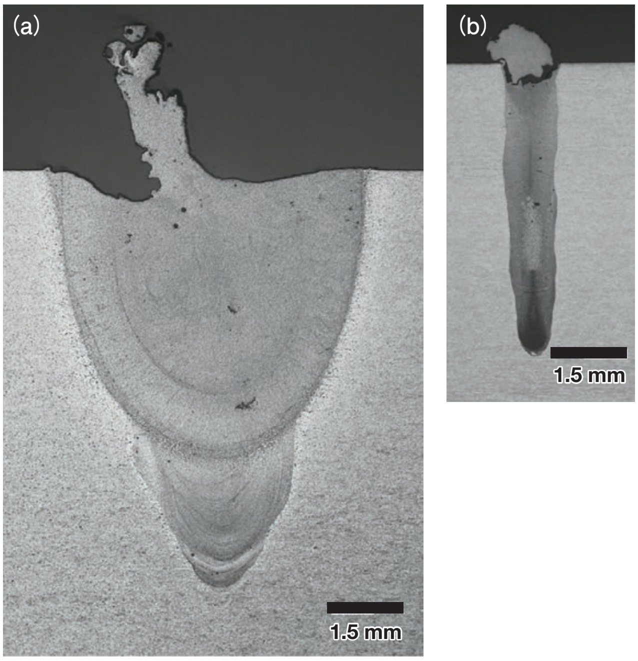


**Figure 6 Cross-sectional view of the aluminum alloy processed with a 6 kW multi-mode fiber laser.**
**(a) 1 m/min (b) 10 m/min**

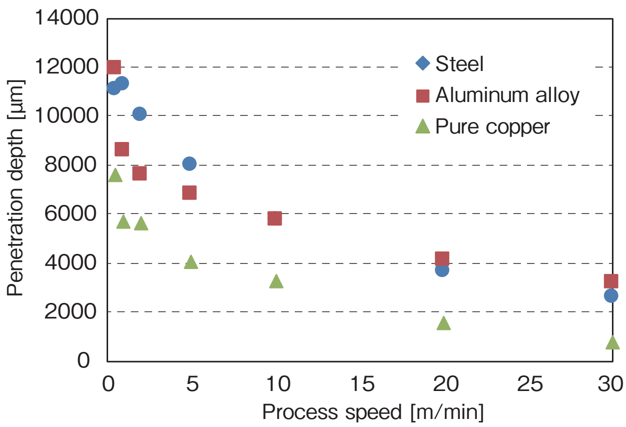


**Figure 7 Penetration depth of various materials processed with a 6 kW multi-mode fiber laser.**

## 3. BEAM MODE CONTROL TECHNOLOGY

As described, the fiber lasers can obtain the local and the deep penetration due to the high beam quality and the high power output. Based on this performance, the improvement in the cycle time during the production and the processing of materials that are difficult to absorb laser light have been made possible. On the other hand, during welding using the fiber laser, the scattering of the molten metal, that is the sputtering, occurs a lot. This sputtering induces various welding defects, decreases in bonding strength and increases with additional processes. Also, if devices are manufactured by using these defected materials, it causes a possibility of decreasing a process yield rate due to the deterioration of the device characteristics. In order to achieve a more efficient production process using the fiber lasers, it is necessary to solve this issue.

Therefore, with the purpose of resolving this issue, the beam mode control technology has been developed jointly with FURUKAWA DENSHI CO., LTD. and the sputtering and the welding defects were successfully suppressed. In this chapter, including the sputtering and the defect suppression on galvanized steel sheet, copper and aluminum are reported.

### 3.1 Sputter Suppression in Steel Materials

The galvanized steel sheet is widely used in automobile bodies and building materials in order to provide antirust and anticorrosive function. However, when this members are welded in close contact, a large amount of welding failures occur due to the zinc vapor generation as shown in Figure 8 (a). This is because the zinc plating on the surface around the melting part of the steel sheet evaporates due to the high temperature, and it is eliminated as vapor during welding. Therefore, at present, the following method is mainly adopted. Gaps about 0.1 to 0.3 mm are formed between the steel sheets, and the zinc vapor generated by the welding is eliminated from these gaps. However due to some restrictions in this method, such as the choice in the welding shape being limited because of the complexity of jigs and the necessity of eliminating the vapor towards all sides of the welding point, issues are raised regarding the necessity to simplify the construction method by introducing the fiber lasers and the inherent fact that there is no degree of freedom in shape designing.

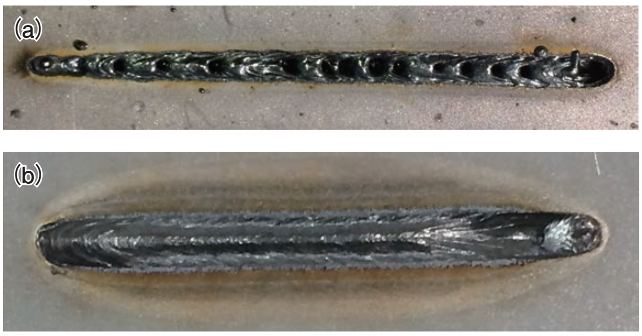


**Figure 8 Images of the welding beads on the galvanized steel sheet.**
**(a) With the conventional single focused spot**
**(b) With the beam mode control technology**

By proceeding with the development of the beam mode control technology, we succeeded in welding the galvanized steel sheets overlapped without gaps as shown in Figure 8 (b). In regard to the inside, it can be confirmed that inside defects are suppressed as shown in Figure 9.

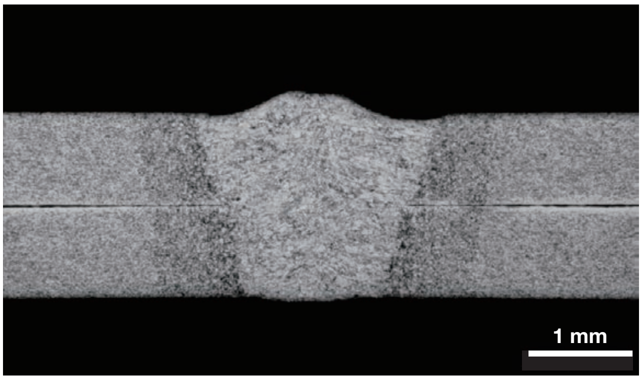


**Figure 9 Cross-sectional view of the galvanized steel sheet processed with the beam mode control technology.**

### 3.2 Suppression of the Sputtering and the Welding Defects in Nonferrous Metals

Copper and aluminum are difficult materials to absorb the laser light of 1070 nm, and until the fiber laser was developed, the processing with the laser was very hard. However, recently, these materials are becoming possible to be processed with the high power density of the fiber lasers. In recent years the driving of electric automobiles has been encouraged. Aluminum can contribute to the weight reduction of the automobiles. And, copper is used in large quantities in electric devices. So the fiber laser welding process of aluminum and of copper are very attractive because the production efficiency can be improved.

On the other hand, when the laser light is applied to copper for melting, as shown in Figure 10 (a), other than the sputtering, defects like hollowed holes called blowholes are formed on the surface. Once this defect is formed, when it is used in devices, not only the appearance is damaged but also increase in electrical resistance and decrease in thermal conductivity are induced, and in worst case the device will not be able to be in functional.


**Figure 10 Images of the beads on the pure copper sheet.**
**(a) With the conventional single focused spot**
**(b) With the beam mode control technology**

By developing the optimum beam mode control technology for the pure copper, we succeeded in the copper welding without any blow holes as shown in Figure 10 (b). Applying this technology, 50 copper sheets (8 μm thickness each) were overlapped and welded, the result is shown in Figure 11. In the welding with the normal fiber laser, the copper foils were torn as shown in Figure 11, while in the welding with the beam mode control technology the copper foils were neatly welded to the inside without breaking as shown in Figure 11 (b) (c). Also for aluminum, the suppression in sputtering was confirmed as shown in Figure 12.

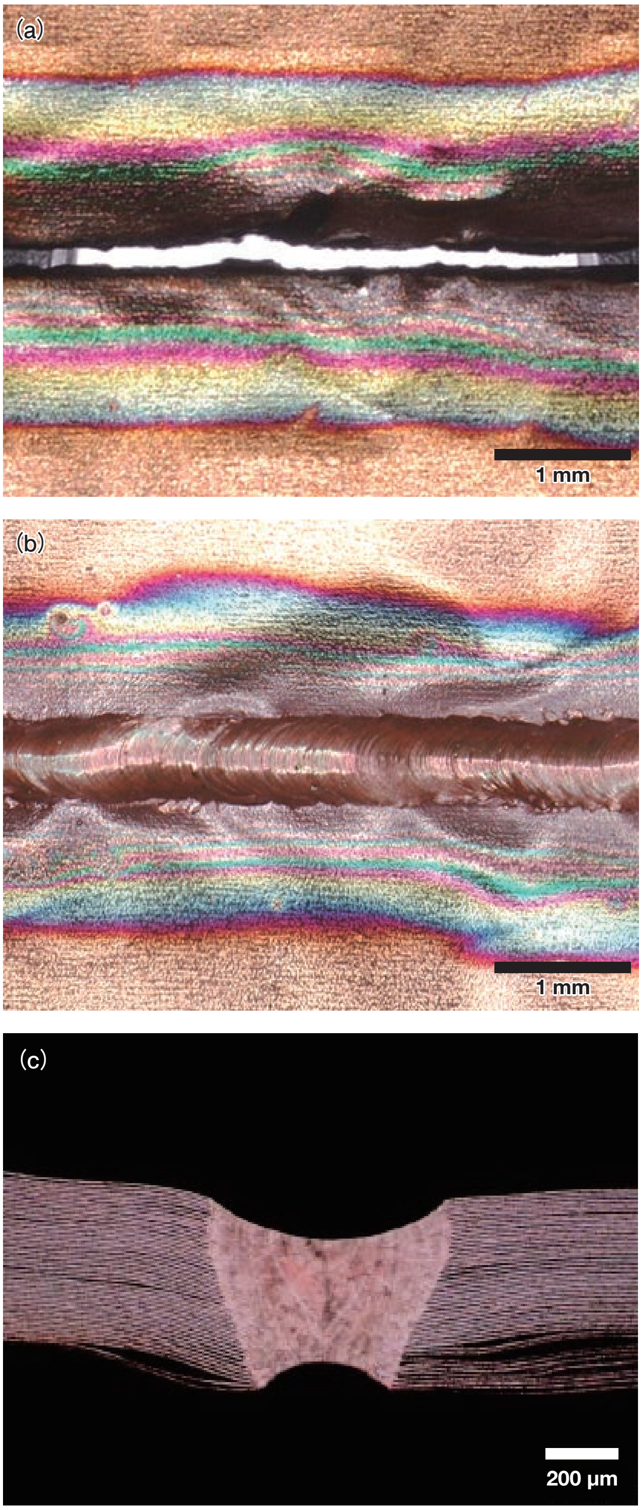


Figure 11 Images of the welding beads on copper foils.
(a) With the conventional single focused spot
(b) With the beam mode control technology
(c) Cross section of (b)

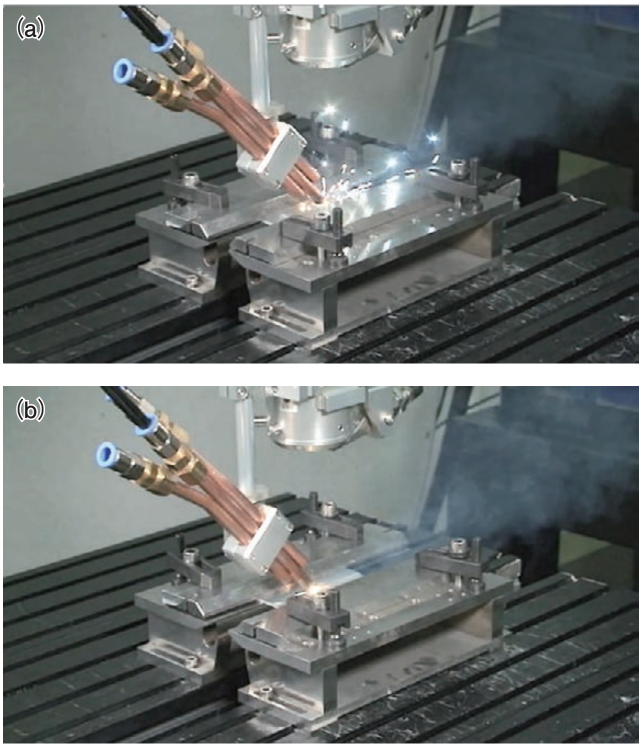


Figure 12 Aluminum plates welding.
(a) With the conventional single focused spot
(b) With the beam mode control technology

## 4. CONCLUSION

This paper reported the basic processing characteristics of the fiber laser manufactured by FEC, also reported is the beam mode control technology that can suppress the sputtering and processing defects for various materials. We believe that by utilizing these technologies we will be able to contribute to the society needs in the coming EV conversion and in the high efficiency production technologies. And we would like to propose expanding these production technologies.

Furthermore, we will proceed further development and will propose more attractive laser processing solutions.