Fiber Laser Welding Cuts Costs and Improves Results

Excelling arc welding and CO_2 lasers at keyhole welding

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Lasers have been employed in a variety of welding applications for many years. And, as laser technology further develops and diversifies, its uses in welding continue to expand. This article provides an overview of high power lasers in keyhole welding. It then examines the characteristics and advantages of fiber laser sources for welding from Coherent-Rofin, in particular, and reviews a specific application that has benefitted from these lasers.

Most traditional (non-laser) welding techniques currently in use are variations of arc welding. In these methods, two pieces of metal are first brought into contact or close physical proximity. The edges of the pieces may have been shaped to facilitate their joining. A high voltage is established between an electrode and the contact region, creating an arc which melts the material – or, in some cases, an additional filler material or the electrode itself. The melted material fills any gap between the workpieces, or overlays them, and then solidifies to join the parts.

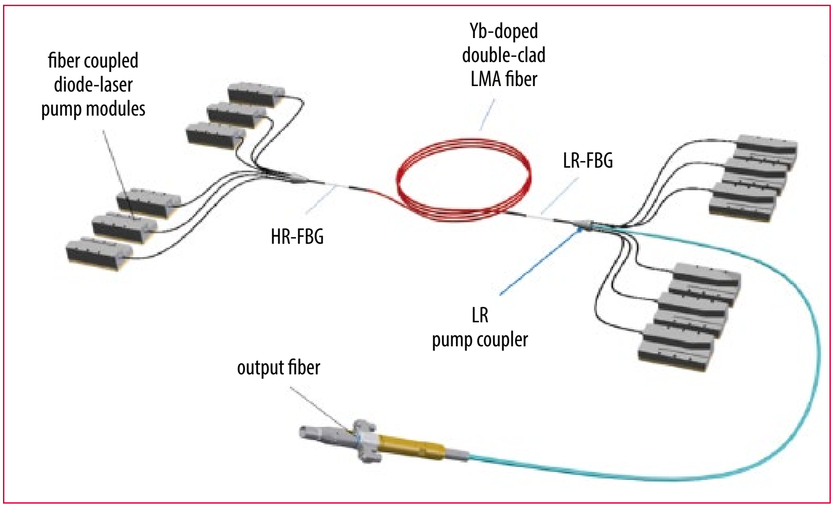

Fig. 1 Coherent-Rofin fiber laser oscillator schematic, including twelve diode laser pump modules, and 6 × 1 fiber coupling modules which inject pump light into the gain fiber, and allow efficient extraction of the laser output.

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The primary advantage of most arc welding methods is their relatively low cost, particularly in terms of the capital equipment expenditure. Furthermore, arc welding techniques are well understood and widely employed, and standards for producing and testing them are well established, so there's not much of a learning curve in bringing these processes on line.

The major disadvantages of arc welding mostly derive from subjecting parts to high heat. This can result in microstructures in the melted material that yield poor strength in the weld joint, and a relatively large heat affected zone in the material adjacent to the weld. Additionally, the parameters of the arc are influenced by the local electric field, and can therefore not be set independently.

Laser keyhole welding

Most laser welding techniques can be classified into two basic categories, "keyhole" and "conduction mode" welding. Both of these welding modes are capable of being performed autogenously, that is, without filler metal, as well as with filler, if so desired.

Keyhole, or deep penetration welding, is commonly encountered when welding thicker materials at high laser powers. In keyhole welding, the laser is focused so as to achieve a very high power density at the work piece. At the focus of the laser beam, the metal actually vaporizes, opening up a blind hole (the keyhole) within the molten metal pool. Vapor pressure holds back the surrounding molten metal and keeps this hole open during the process. The laser power is mainly absorbed at the vapor melt boundary and the keyhole walls. The focused laser beam and the keyhole continuously move along the welding path. At the front of the keyhole, new material is molten, and at the back, it resolidifies to become the welded joint.

The small size of the keyhole region results in a precise, narrow fusion zone,

with a high aspect ratio (depth to width) as compared to arc welding methods. Furthermore, the highly localized application of heat means that bulk of the work piece acts as an effective heat sink so the weld region heats up and cools down rapidly. This minimizes the size of the heat affected zone, and reduces grain growth. Thus, the laser can generally produce stronger joints than arc welding, which is one of its primary benefits.

Laser welding also offers greater flexibility than arc welding, since it is compatible with an extremely broad range of materials, including carbon steel, high strength steel, stainless steel, titanium, aluminum, and precious metals. It can also be used to join dissimilar materials, as differences in material melting temperatures and heat conduction are of minor importance in the process.

In addition, laser welding delivers significant cost advantages over traditional methods, when all the process steps are considered. In particular, the precise application of heat minimizes distortion in the weld and overall part, thus eliminating the need for post processing in many cases. Plus, the ability to project the laser beam over relatively long distances with essentially no power loss makes it easy to integrate laser welding with other production processes, and lends itself well to integration with manufacturing robotics. Last, but not least, new product configurations with reduced flange sizes can be realized, which is critical for light weight vehicles in the automotive industry.

Fiber lasers for welding

Modern CO_2 and fiber lasers easily deliver the beam parameters and power requirements for keyhole welding. Since almost all metals become increasingly absorptive at shorter wavelengths, process efficiency is enhanced at the shorter fiber laser wavelength of ~ 1 µm, as compared to CO_2 laser wavelength of 10.6 µm.

Fiber lasers, in particular, match the requirements of keyhole welding extremely well. They typically offer output powers in the range of 500 W to 10 kW, and can readily achieve focused spot sizes in the necessary range between 40 µm and 800 µm, even at relatively large working distances. From a practical standpoint, the use of a beam delivery fiber expands integration options and facilitates the use of the laser in the manufacturing environment. Finally, the high reliability, excellent uptime and favorable cost of ownership characteristics of fiber lasers make them an economically viable and attractive choice for production welding applications.

There are currently several manufacturers of high power fiber lasers for welding and other materials processing applications. Coherent-Rofin fiber lasers, in particular, have been designed to deliver a combination of performance, reliability, ease of integration and cost characteristics that is optimum for welding and other materials processing applications. To understand how this is achieved, it's useful to examine some of the design and construction details of these lasers.

The drawing (Fig. 1) shows the main elements of the fiber laser. The laser resonator is formed by a large mode area (LMA), Yb-doped, double clad optical fiber and fiber Bragg gratings for resonator mirrors. This is pumped from each end by a series of diode laser pump modules, whose outputs are fiber coupled into the gain fiber.

Based on this design, one set of pumps and gain fiber can produce output powers of up to 3 kW. The output from up to four of these single mode fiber laser units can then be combined into one multimode fiber to achieve powers of up to 10 kW. Alternately, the Coherent-Rofin "standard" cabinet supports splitting the output from a single fiber laser into four separate fibers through the use of the integrated fiber-to-fiber switches.

Thus, this modular construction approach offers several options in terms of output power, delivery fiber diameter, and beam parameter product. The benefit is the ability to readily adapt the laser beam characteristics to precisely match the exact requirements of a specific process.

Some users have experienced fiber laser damage or process inconsistencies caused by back reflections when processing highly reflective metals, such as copper and brass. Coherent-Rofin lasers utilize an optimized power generation and delivery technology, as well as sensors at different positions within

Fig. 2 Two models of towel heater, produced by a Russian manufacturer using an automated welding system from Rodomach which is based on a Coherent-Rofin fiber laser.

Fig. 3 Complete system for automated welding of towel radiators.

the system, to protect laser components from such damage. These safeguards eliminate the problem of back reflections, and allow reliable welding of brass, aluminum and copper without any concern for damaging the laser.

Of course, the fiber laser is just one part of the entire welding system, which also includes a beam focusing welding head, as well as control electronics. In addition to fiber lasers, Coherent-Rofin also offers beam delivery components which mount into customers' machines. These can be fixed optics or complete, integrated scanning solutions, which include control of all relevant laser parameters, to fully optimize the welding process. Moreover, these integrated solutions often feature fast and flexible beam scanning technology which allows rapid beam movement from one welding contour to the next. This increases the productivity of a laser processing system enormously.

Case study: laser-welded towel radiator

Steam radiators for heating towels have become popular at gyms and spas worldwide. A Russian manufacturer of these towel heaters now employs an automated welding system, developed by the Dutch special purpose machine manufacturer Rodomach, which is based on a Coherent-Rofin fiber laser.

Previously, the radiator manufacturer had utilized the traditional TIG (tungsten inert gas) arc welding method by hand in their production. The goal of the radiator manufacturer was to transition all their manufacturing to an automated system. This meant that the process would have to be able to accommodate a variety of different product configurations, including models with round pipes, as well as those having pipes with various other shapes. For all these products, the desired welding depth is 100 % of the pipe thickness, and the final assembly must withstand air pressures of 25 bar. Product appearance is also critical in this application, and the manufacturer wanted to achieve a uniform, smooth seam weld, which is attractive and requires no post processing. This is necessary because the final step in their production is electropolishing, which brings the stainless steel radiators to a mirror finish.

In order to develop a laser-based solution for this process, Coherent-Rofin ran trials for Rodomach at the Hamburg Applications Laboratory. These proved that the austenitic Cr-Ni-Steel AlSI 304 used by the radiator manufacturer was easy to laser-weld. However, standard tooling could not ensure an optimum fit between parts for the entire operation, and a consistent, high quality seam could therefore, not be guaranteed.

Therefore, the companies undertook to design an approach which would clamp the part in a way which enables consistent welding, and also prevents part warping during the process. The particular solution was to replace the traditional, static clamp tooling used for welding with a servo-controlled clamping mechanism having integrated cooling. This method evenly clamps the part at all welding points, while the cooling prevents the joints from warping.

The testing showed, that a 2-kW fiber laser (Coherent-Rofin FL 020) with a 300 µm delivery fiber, and focusing optics having a focal length of 300 mm, is the perfect fit for this application. This optical configuration provides a long depth of field, allowing the customer a high degree of process tolerance. The result is reduced scrap and improved productivity.

Rodomach configured the system so that, through the use of a beam switch, a single fiber laser can feed two robotic welding stations which alternately process the two sides of the radiator. Rodomach pooled the control of the system, the two robots, and the laser on to one terminal, to simplifie the operation for the customer. The final system operates at a welding speed of 2 m/min, and provides high quality welds which can withstand 250 bars of steam pressure, which is ten times their original specification.

In conclusion, high-power fiber lasers have emerged over the past decade as an ideal tool for a wide range of welding applications. But, successfully deploying a fiber laser in a specific application requires more than just a high quality source. In particular, partnering with a fiber laser company that offers support and expertise in process development and integration, together with a worldwide support infrastructure, is critical not only to getting products to market, but also for long-term success.

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