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An Approach to Best Welding Practice. Part – XXI. Section – III- BV-A

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"AN APPROACH TO BEST WELDING PRACTICE. Part – XXI." is the **Twenty First** Detail Part of **"AN APPROACH TO BEST WELDING PRACTICE"** which was written as a General and Overall approach to the subject matter.

AN APPROACH TO BEST WELDING PRACTICE. Part – XXI., Section III –BV-A is particularly focused on the Generation and Computer based Storage of Welding Data on Laser Welding Process for Fabrication. It is required as a Working Guideline for Planning Engineers, Welding Co-ordinators and Quality Managers working in an Engineering Fabrication Plant using welding as the main manufacturing process.

In fact, this is a lengthy process to develop and as each and every step is connected with each other for cross references, none can be eliminated.

In every Fabrication concern where Welding is the major manufacturing process preparation, recording and storage of welding processes must be done.

The Importance of Record Keeping

Record keeping critical in case of Fabrication and Manufacturing concerns employing welding as the main manufacturing process, as because welding is a "Special Process" and the Product acceptance is dependent upon follow up of a number of Procedures, Codes and Standards. Documentation of all these proceedings are to be meticulously prepared and maintained – normally by the "Welding Engineer" or "Welding Coordinator." Again, apart from documentation so many data related to the Power Source, Electrodes, Gases used, Maintenance schedules etc are to be coordinated with variety of data converging for a product to be manufactured and to be accepted by the customer. Normally, most of these are paperwork and the tendency is either to destroy the past records of papers or to dump them somewhere beyond restoration. Even the large volume of information kept in mind of the Welding Engineer or the Welding Coordinator in course of work are irretrievable to any new incumbent or others.

It is an accepted fact now that data collection, storage and retrieval can not be done effectively with human individuals or even by groups and possibilities of distortion of retrievable data cannot be ruled out.

I. What Data are needed ?

It is understood and accepted that in Fabrication and manufacturing Industries where Welding is the main process, classification of Data used and needed is very difficult. We can at best identify the following needs

1. Welding processes
2. Welding Power Sources with Ancillary Equipment
3. Consumables – Electrodes, Wires, Flux Cored Wires
4. Shielding Gases
5. Joint design weldment design and surface preparation
6. Weld location Welding position

II. How to store and retrieve data ?

A large number of computer softwares have been developed to store data, modify and to retrieve as and when required. This system will eliminate human error, can link and compare past performances with the present one instantly, may even point out optimum use of resources for increased efficiency, effectiveness of resources for ultimate gain of productivity and quality improvement.

An integrated system will include:

- Filler and base metals and their chemical and mechanical properties;
- Histories of welder qualification and the quality of welds by each welder;
- Welding-procedure information, including WPSs, PQRs, and pre- and post weld heat-treatment information;

LASER WELDING

- Design information, including joint design graphics and welding symbol information; Corrosion-resistant and wear-resistant material information, such as ferrite content and prediction for stainless steel welds.

The softwares art all designed to operate in the computing environment of the desktop computer, turning the computer into a welding engineering work station.

Principles of laser Welding

The laser is a high power density process that provides a unique welding capability to maximizen penetration with minimal heat input. The weld is formed as the intense laser light rapidly heats the material – typically in fractions of milliseconds.

The laser beam is focused onto the workpiece by a set of mirrors. These are used because they are much easier to cool than lenses, which are commonly used in lower-power cutting applications. When the laser beam is moved relative to the workpiece, the energy of the focused laser beam melts the metal so that a joint is formed. **Fig.** above shows the welding head of a high-power CO_2 laser.

Laser welding is increasingly being used in industrial production ranging from microelectronics to shipbuilding. Automotive.

Advantage of the many benefits of this technology:

- Low heat input
- Small heat-affected zone (HAZ)
- Low distortion rate
- High welding speed

Hybrid processes involving a combination of laser and MIG arc welding are being developed to reduce fit-up requirements on the parts to be joined, thus improving the most critical aspects of laser welding. The addition of filler wire in GMAW substantially facilitates weld edge preparation. Alloying elements in the filler wire may be used to refine the mechanical properties of the seam. Beyond that, these combined processes can improve the welding speed of the individual processes, weld penetration depth and overall seam geometry.

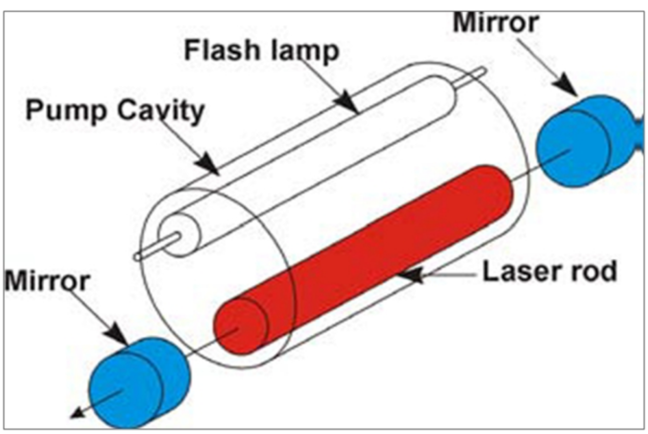
High-power CO_2 lasers (2–10 kW) are used in the welding of car bodies, transmission components, heat exchangers and tailored blanks.

For many years, low-power Nd:YAG lasers (< 500 W) have been used to weld small components, such as medical instruments, electronic packages and razor blades. Nd:YAG, disc and fibre lasers with power levels in the multi-kW range benefit from beam delivery via optical fibres. These are easily manipulated by robots, thereby opening a large field of 3D applications, such as laser cutting and welding of car bodies.

Nd: (YTTRIUM ALUMINIUM GARNET) YAG laser

The laser rod used in Nd:YAG laser welders is a synthetic crystal of yttrium aluminum garnet (YAG). The YAG material is the "host" material, containing a small fraction of neodymium, the active element. The YAG crystal is an ideal host for the lasing material Nd3+, because it is physically hard, stable, optically isotropic, and has good thermal conductivity, which permits laser operation at high average power levels.

Neodymium is an excellent lasing material because it produces a higher level of peak powers than any other doping element. The laser rod dimensions are selected for power and optical quality. The maximum rod size is limited to a diameter of around 15 millimeters (mm) and a length of 200 mm, to ensure crystal quality and thermal management.



Laser welding modes

The laser is a high power density process that provides a unique welding capability to maximize penetration with minimal heat input. The weld is formed as the intense laser light rapidly heats the material – typically in fractions of milliseconds. There are three types of welds, based on the power density contained within the focus spot size:

- conduction mode,
- transition keyhole mode, and
- penetration/keyhole mode.

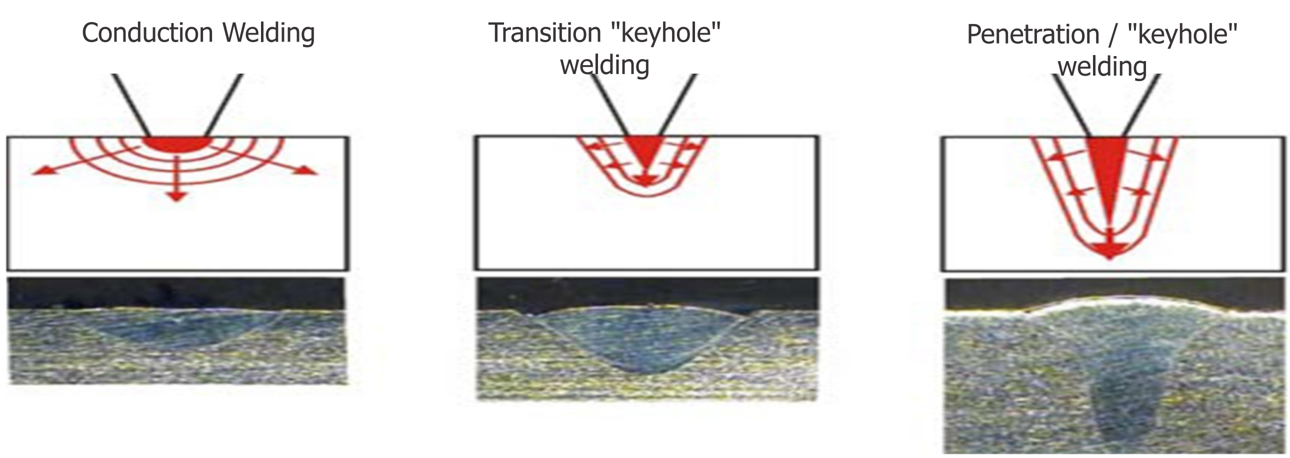
Conduction mode

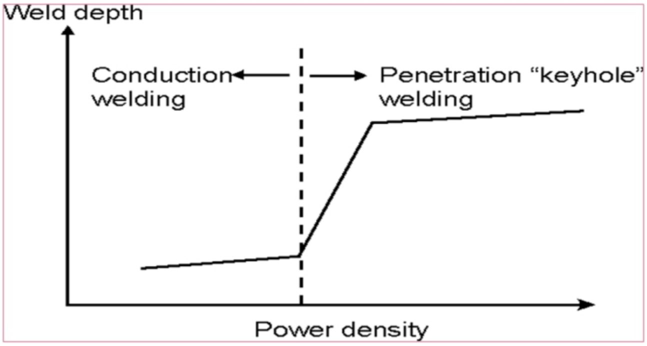
Conduction mode welding is performed at low energy density, typically around 0.5 MW/cm^2, forming a weld nugget that is shallow and wide. The heat to create the weld into the material occurs by conduction from the surface. Typically this can be used for applications that require an aesthetic weld or when particulates are a concern, such as certain battery sealing applications.

Transition mode

Transition mode occurs at medium power density, around 1 MW/cm^2, and results in more penetration than conduction mode due to the creation of what is known as the "keyhole." The keyhole is a column of vaporized metal that extends into the material; its diameter is much smaller than the weld width and is sustained against the forces of the surrounding molten material by vapor pressure. The depth of the keyhole into the material is controlled by power density and time.

Keyhole or penetration mode – Increasing the peak power density beyond 1.5 MW/cm^2 shifts the weldmto keyhole mode, which is characterized by deep narrow welds with an aspect ratio greater than 1.5. **Figure** shows how the penetration depth rapidly increases when the peak power density is beyond 1 MW/cm^2, transitioning the weld mode from conduction to keyhole/penetration welding.





Relationship between power density and weld mode

Penetration or keyhole mode welding is characterized by narrow welds. This direct delivery of laser power into the material maximizes weld depth and minimizes the heat into the material, reducing the heat affected zone and part distortion. mIn this keyhole mode, the weld can be either completed at very high speeds – in excess of 20 inches per second with small penetration typically under 0.02-inch (0.5 mm) – or at lower speed, with deep penetration up to 0.5-inches (12 mm).

Role of the welding gas

Welding gas plays an important role in laser welding. Apart from protecting the molten and heat-affected areas of the workpiece against the ambient atmosphere, it also increases the welding speed and improves the mechanical properties of the weld.The welding gas is directed to the workpiece through a nozzle system inorder to protect molten and heated metal from the atmosphere. However, the welding gas has other functions, too. It protects the focusing optics against fumes and spatter and, in the case of CO_2 lasers, also controls plasma plume formation. The welding gas can be made to play an active role in the welding process, such as increasing the welding speed and improving the mechanical properties of the joint.

Pulsed and continuous wave operation

A weld can be created either as an individual spot or a seam weld. The laser output that creates these welds can be achieved in one of two ways:

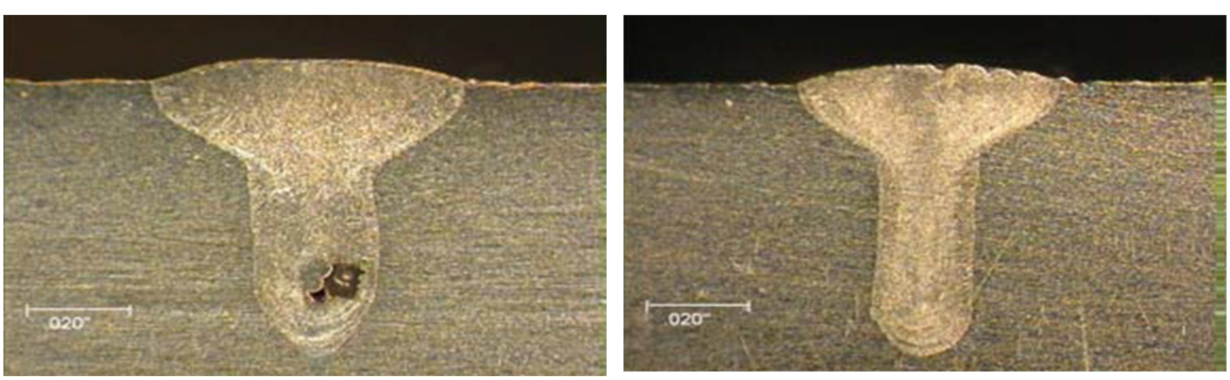
A pulsed laser produces a series of pulses, discrete packets of energy, at a certain pulse width and frequency until stopped. The "pulsed" descriptor refers to a laser that can produce a peak power that is greater than its average power. A continuous wave (CW) laser produces extended output – the laser remains on continuously until stopped. For example, a 25 W pulsed Nd:YAG laser can produce peak powers of up to 5 kW for a few milliseconds. This means it can produce a spot weld that would require a CW laser sized at 5 kW! With pulsed lasers a seam weld is created by a series of overlapping spot welds.

For a continuous weld the laser remains on for the duration of the seam. A CW laser can also produce discrete pulses of laser light – known as gated or modulated output. In this case the CW laser peak power does not exceed the laser's rated average power. An Nd:YAG laser operates only in pulsed mode; diode lasers operate in continuous wave; and fiber lasers can operate in both modes.

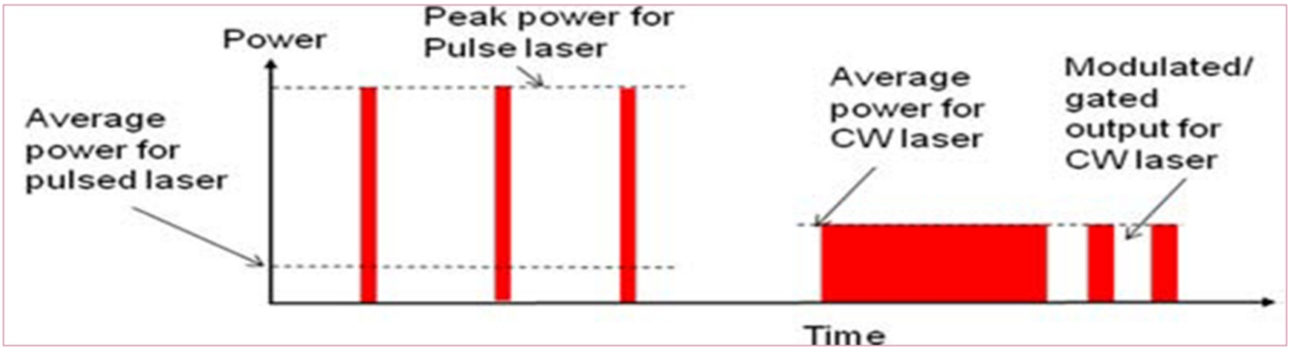
Choosing when to use pulsed, continuous wave, or modulated output is determined by the specific application. Spot welding typically uses pulsed operation. For seam welding, the selection is made based on heat input and cycle time. For instance, when seam welding an implantable device, a pulsed laser is used to minimize heat input and maintain a uniform weld around a complex geometry with varying welding speeds. In contrast, for airbag initiators, welding at high speed using CW operation is favoured.

Time share and energy share

A single laser can have multiple outputs, which can support single weld heads in multiple workstations or multiple weld heads in a single workstation. These multiple outputs from the



Welds using argon (left) and nitrogen (right) on stainless steel

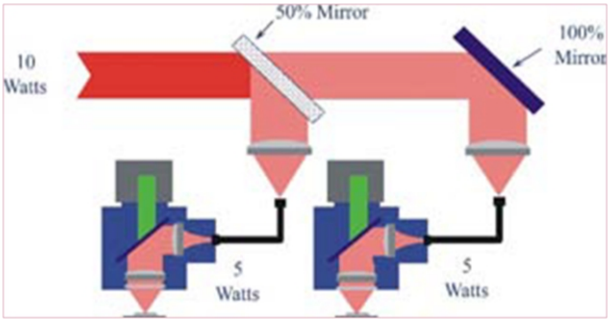


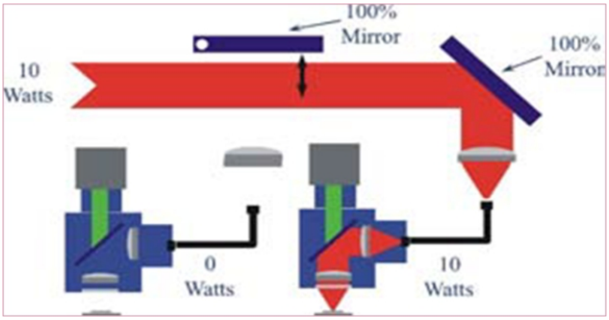
Comparison of laser outputs : pulsed, CW and modulated

laser can be fired sequentially or simultaneously. Sequential firing is known as time share and simultaneous firing is known as energy share. Sharing multiple beams from a single laser can offer productivity and cost benefits. Use of time or energy share can be financially quite attractive because laser costs can be offset by increased utilization efficiency. Energy sharing (**Figure 19**, left diagram) offers simultaneous processing, while time sharing (right diagram) offers serial proc

Material Selection

Selecting a material that satisfies both part functionality and manufacturability is fundamental to a Successful laser welding process. The most common material used for micro welding is 300 series stainless steel, along with aluminum alloys and titanium. This contrasts with penetration welding, where many forms of carbon steel are welded. **Table 1** summarizes the weldability of the most common materials used.





QBH style diverging beam output vs a QCS style collimated output

Table : General Material Selection Guidelines

Material	Comments
Aluminium	1050, 3003 and 6061 to 4047 are OK. Continuous wave welding increases weldability of alloys such as 5052 and 5082. Aluminum alloys should be teste thoroughly for crack sensitivity
Beryllium copper	Good welds. Potential safety hazard exists from the beryllium oxide fumes
Carbon steel	Good welds. Carbon content should be less than 0.12% for pulsed welding, upto 0.2% for continuous wave welding
Copper	Good welds. High energy levels required to overcome surface reflectivity unless 532 nm wavelength welding laser used.
Nickel alloys	Good welds, especially with alloys such as Hastelloy-X, Inconel 600 and 718
Nitinol	Good welds. Care needed to avoid brittleness
Phosphor bronze	Good welds
Stainless steel	304 and 304L produce excellent welds 316 and 316L are OK provided Cr/Ni ratio is greater than 1.7 303 is not recommended due to cracking tendencies. Can be matched with friendlier materials such as 304. A CW laser can be used to increase weldability. 400 series require testing for crack sensitivity.
Titanium	Good weld

Joint design and fit-up

Laser welding is a non-contact process that requires only single-sided access, so a wide range of joints geometries can be welded. The most common weld joint designs are shown in **Figure 26**. Most other types used are a variation of these.

The most significant requirement for reliable laser welding is a close fit-up at the joint interfaces. Laser spot or seam welding is usually an autogeneous process, which means that no filler material is added during the welding process. Therefore, if the welding interfaces are too far apart, there is insufficient weld material to bridge the gap – or the weld will be undercut or under-filled. This is especially important to consider when migrating from other welding processes that use filler materials for bridging gaps between parts.

As a rule of thumb, the gap should never be more than 10 percent of the thinnest material or of the weld penetration, whichever is less. It must be stressed that gap tolerance is case-specific, and should always be fully examined and quantified by actually welding production parts. **Figure 27** shows the recommended maximum gap for different weld joint designs.

In certain cases the fit-up variance may be accommodated by superimposing motion of the beam laterally to the welding direction. This is achieved using a scan head implementing the "wobble" function. The spot size remains constant and the amplitude of the lateral motion is adjusted according to fit-up. **Figure 29** shows a schematic of a single mode fiber laser and scan head that would enable the tailored weld profiles shown in the photos below the diagram.

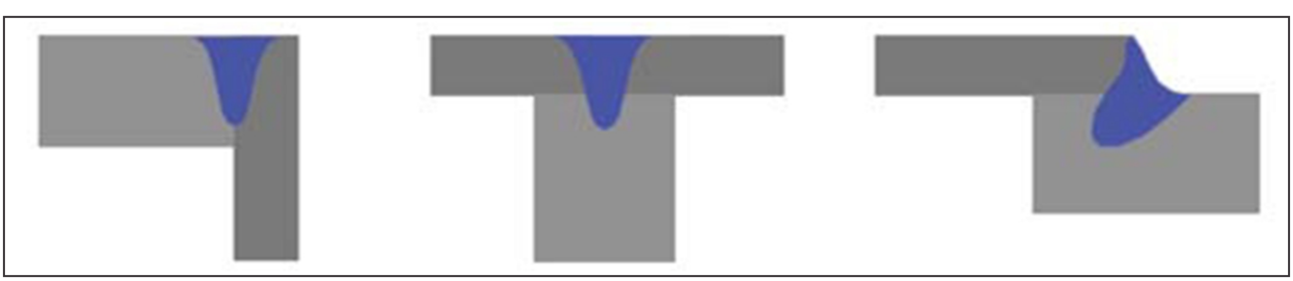
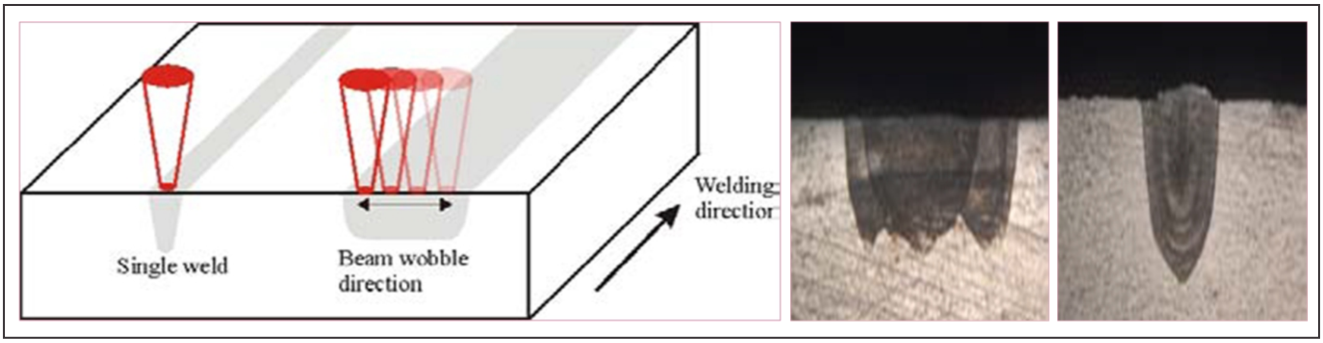


Figure – Recommended maximum gap for weld joint designs



Schematic of single mode fiber laser with and without wobble Optical spot size

The optical spot size is the diameter of the focused laser spot on the work piece.

Figure illustrates these relationships, with a top surface view of a single spot weld.

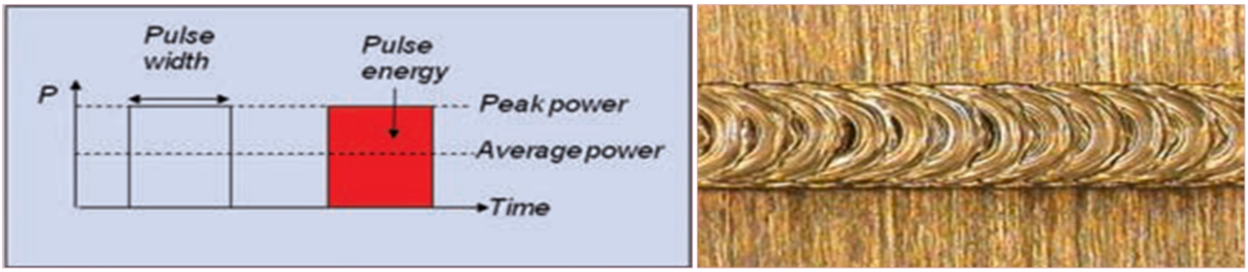


Figure shows the l surface of the weld and how the seam is comprised of individual overlapped spot welds

Optimizing peak power and pulse width

For both pulsed and modulated/gated welding the peak power and pulse width are the key parameters to optimize.

- The peak power is the main parameter for the weld, and is used to control penetration
- Pulse width is a fine tuning parameter that is used as a fine adjust to penetration and weld width, as well as stabilization of the weld if needed
- The pulse repetition rate or pulse frequency controls the heat into the part and thermal heat cycle for a seam weld.

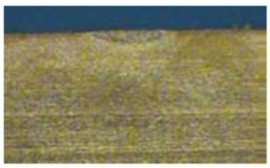
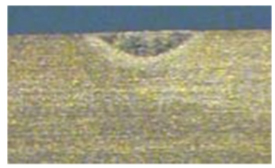
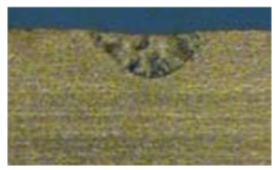
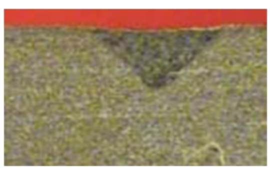
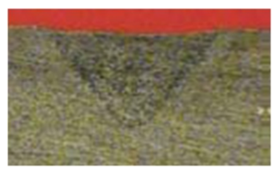
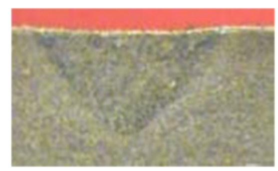
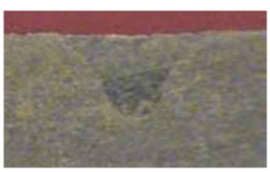
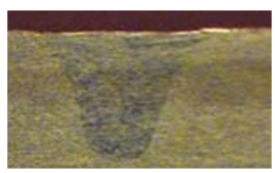
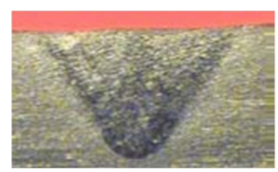
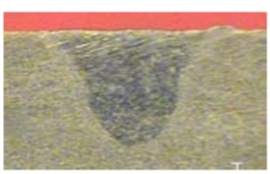
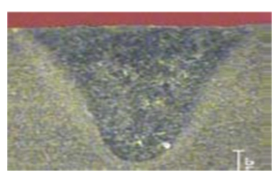
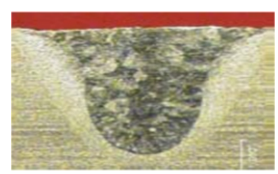
PEAK POWER	PULSE WIDTH		
	2MS	4MS	7MS
0.25 KW			
0.5 KW			
0.75 KW			
1.0 KW			
1.25 KW			

Figure shows the effects of increasing pulse width and peak power on weld dimensions.

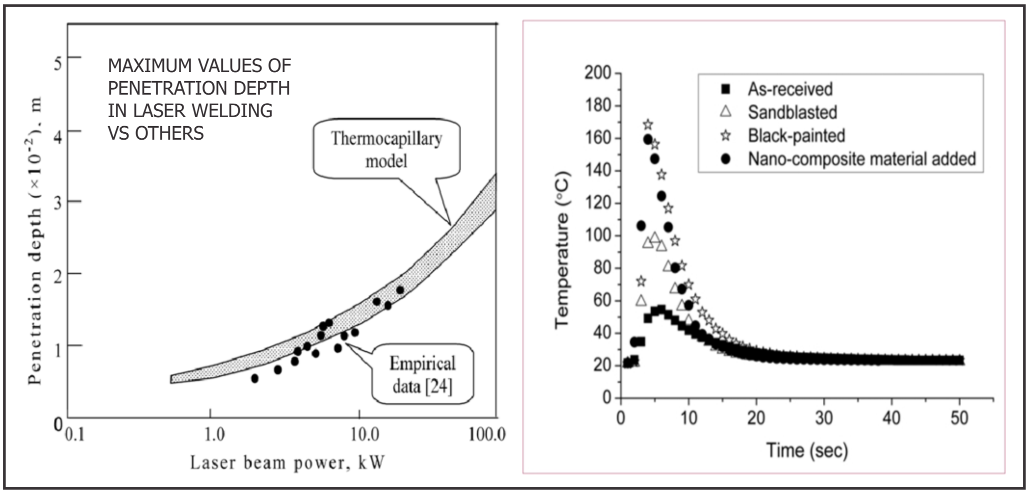
Fiber Laser Welding Process Parameters for 304 SS

Date Set	Laser Power (W)	Welding Speed mm/sec
1	1000	18.33
2	1000	16.67
3	1000	15.00
4	1000	13.33
5	900	18.33
6	900	16.67
7	900	15.00
8	900	13.33
9	800	18.33
10	800	16.67
11	800	15.00
12	800	13.33

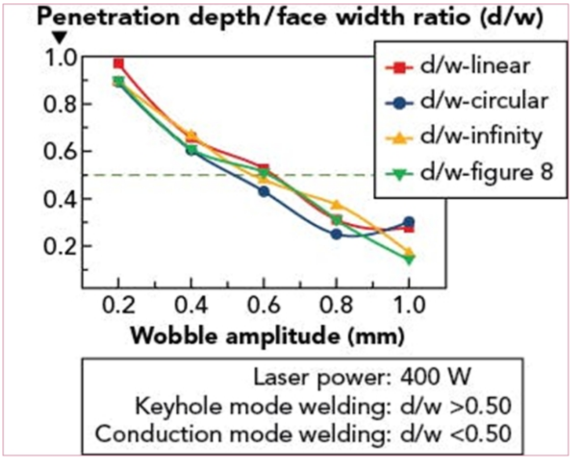
Table 1 - Advantages of Laser Welding
Lower capital equipment costs – cost advantage over EBW • No physical constraints of an enclosure or vacuum chamber enables simplified setup, rapid cycling, and less complex single station tooling
Shorter cycle than EBW times translate to lower cost
Simpler tooling requirements than EBW
Small heat affected zone
Scalable (1 laser servicing several platforms)
Many OEMs support the technology
Lower training costs than EBW
No x-rays generated

Laser Beam Welding for Austenitic SS

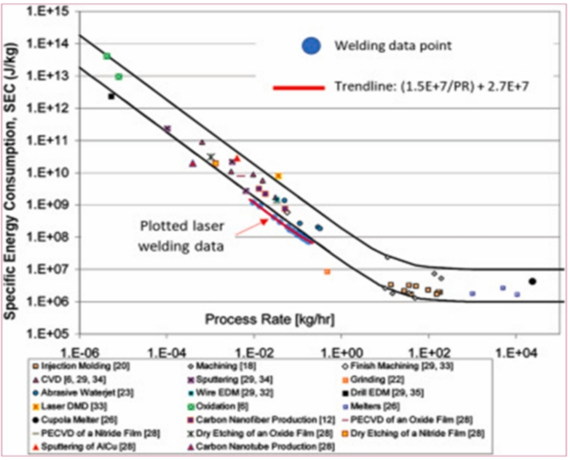
Laser Power (KW)	Welding Speed (mm/min)	Defocussing Distance (mm)	Shielding Gas Type & Flow Rate (l/min)	Gap Between Sheets (mm)	Zinc Removal Prior to Welding
2.5	3	-0.1	ARGON 15-30	NIL	NO
2.5	3	-0.1	HELIUM 15-30	NIL	NO
2.5	3	-0.1	ARGON 15	0.025 - 0.3	NO
2.5	3	-0.1	HELEUM 15	0.025 - 0.3	NO
2.5	3	-0.1	ARGON 15	NIL	YES
2.5	3	-0.1	HELIUM 15	NIL	YES



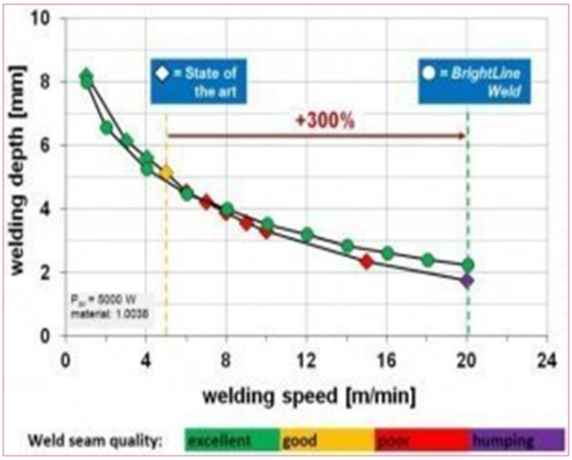
Temperature of Laser Welding of Pure Copper



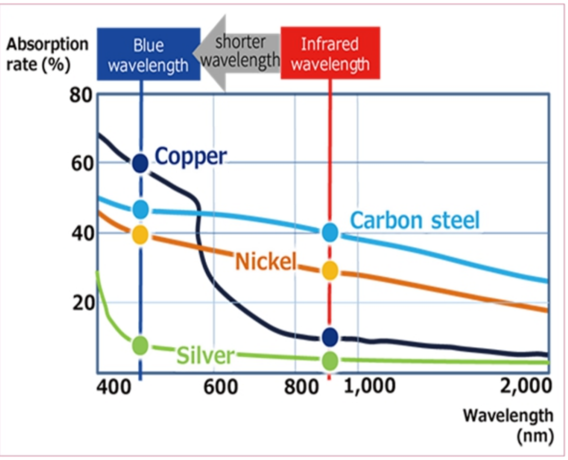
Advanced Laser Fiber Welding.



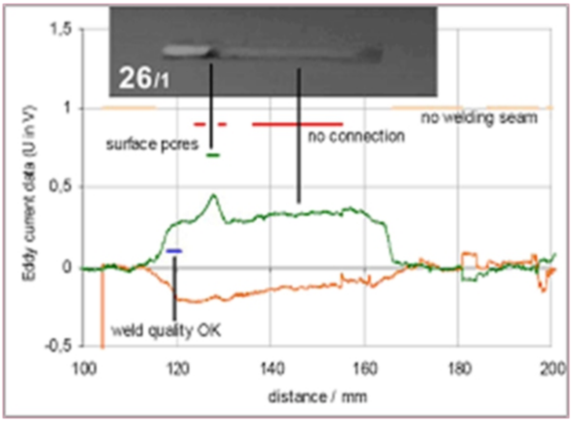
Mathematical for Energy Efficiency



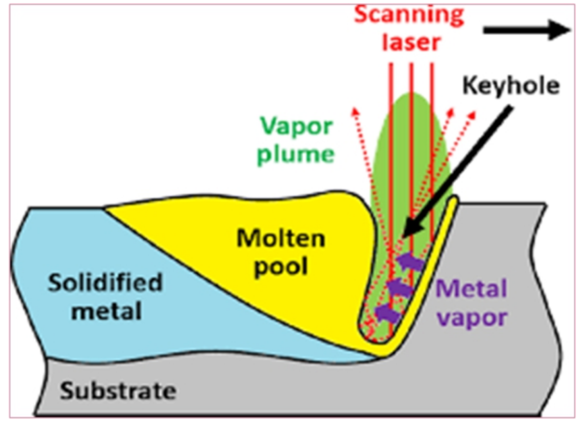
Bright Line Weld – In Laser Welding .



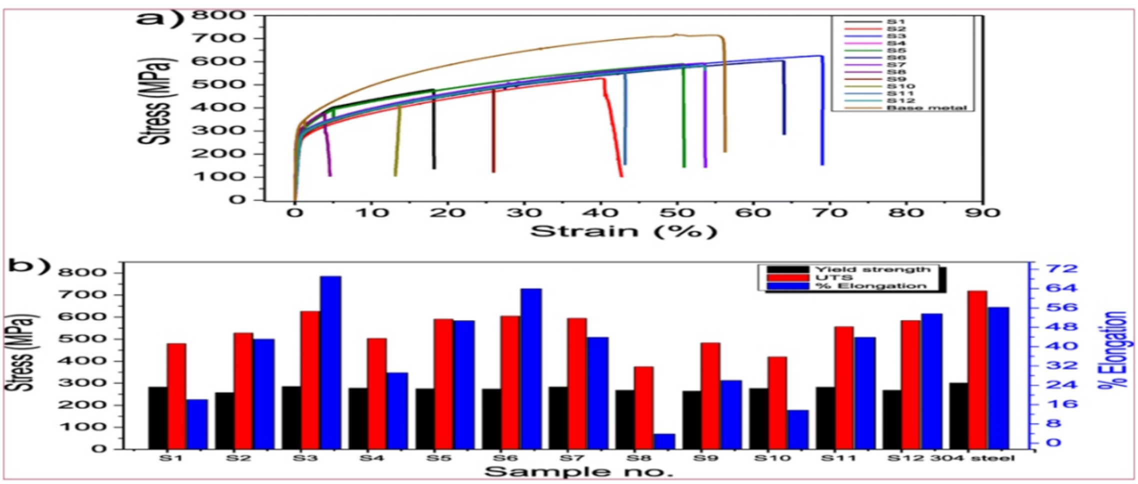
Blue Direct Diode Laser / Laser Welding Robots



Quality Assessment in Laser Welding



Effect of Laser-matter Interaction on Molten Pool Flow and Key Hole Dynamics



Stress-strain Data of AIAI 304 SS Laser