# Welding Technology

# Plasma Arc Welding

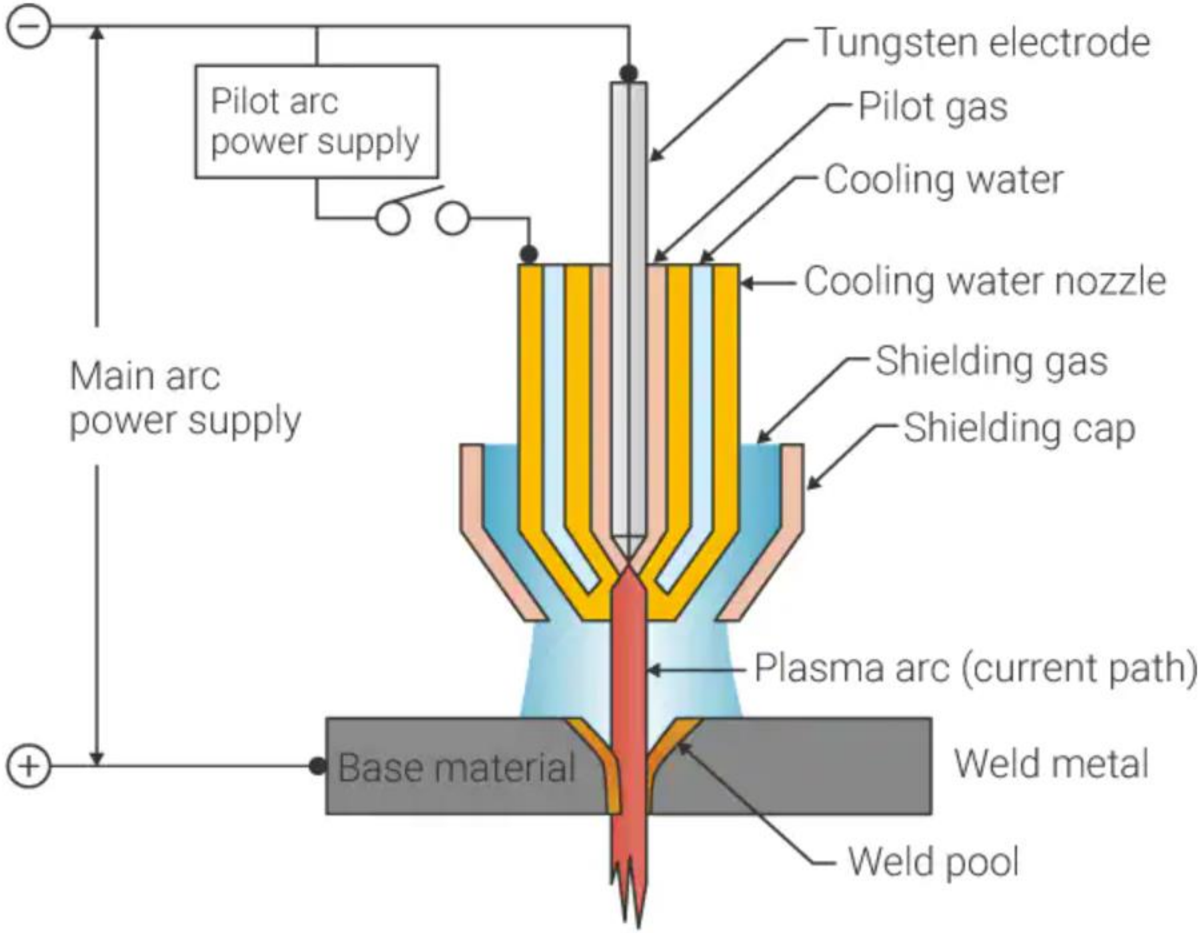
Plasma Arc Welding (PAW) is an arc welding process that employs a high-temperature, constricted plasma gas column to obtain the melting.

Plasma is a hot, ionized gas consisting of approximately equal numbers of positively charged ions and negatively charged electrons. The characteristics of plasma are significantly different from those of ordinary neutral gases, which is why it is considered a distinct fourth state of matter.

Simply put, plasma is a gas that has been superheated to a point where it becomes highly conductive. In welding and cutting processes, this allows for the transfer of electrical current. A plasma arc's temperature can reach as high as 30,000 degrees F.

Plasma welding, first introduced as a welding process in the early 1960s, was used in special low-current applications (microplasma) from 0.5 amp or lower, or up to 500-amp applications for heavy industry.

# Plasma Arc Welding



# Plasma Arc Welding

The PAW works on the principle when a sufficient amount of energy is provided to any inert gas, some of its electrons are released from their nucleus but travel with it.

After the electrons move, the atoms are converted into a hot ionized state. This is the most common condition of the substance which is known as the fourth state of matter.

These ionized atoms have high temperatures that are used to join the two plates. This is the basic principle of PAW. This welding is a form of TIG welding in which a non-consumable tungsten electrode is used to generate the arc.

# Equipment of Plasma Arc Welding

Following are the equipment of PAW:

Plasma arc torch

Shielding and Plasma Gas Supply

Filler Metal

Power Source

Initially, the workpieces are cleaned thoroughly. The power source supplies the power that produces an arc between the tungsten electrode and nozzle, or the tungsten electrode and the workpiece. The tungsten electrode gives a high-intensity arc used for ionization of gas particles and converts gases into plasma.

This hot ionized gas is provided to the welding plates by a small hole. Shielding gases such as argon etc are supplied through pressure valve and regulating valves to the external nozzle of the welding torch.

These gases form a shield around the welding area which protects it from atmospheric gases such as oxygen, nitrogen, etc. The plasma collides to the welding plates and turns it into one piece. The next welding is carried in the direction of welding. If this welding process requires filler material, it is fed manually by the welder.

# Keyhole Welding Process

Another method of using the plasma welding process is the keyhole method of welding. The plasma jet penetrates through the workpiece and forms a hole, or keyhole. Surface tension forces the molten base metal to flow around the keyhole to form the weld. The keyhole method can be used only for joints where the plasma can pass through the joint. It is used for base metals 1/16 to 1/2 in. (1.6 to 12.0 mm) in thickness. It is affected by the base metal composition and the welding gases. The keyhole method provides for full penetration single pass welding which may be applied either manually or automatically in all positions.

# Plasma Arc Welding

The plasma arc is normally operated with a DC, constant current (drooping) characteristic power source. Because its unique operating features are derived from the special torch arrangement and separate plasma and shielding gas flows, a plasma control console can be added on to a conventional TIG power source. Purpose-built plasma systems are also available.

Although the arc is initiated using HF, it is first formed between the electrode and plasma nozzle. This 'pilot' arc is held within the body of the torch until required for welding then it is transferred to the workpiece. The pilot arc system ensures reliable arc starting and, as the pilot arc is maintained between welds, it obviates the need for HF re-ignition which may cause electrical interference.

The electrode used for the plasma process is tungsten-2% thoria, and the plasma nozzle is copper. The plasma nozzle bore diameter is critical and too small a bore diameter for the current level and plasma gas flow rate will lead to excessive nozzle erosion or even melting.

Normal gas combinations are argon for the plasma gas, with argon or argon plus 2 to 5% hydrogen for the shielding gas. Helium can be used for plasma gas but because it is hotter this reduces the current rating of the nozzle. Helium's lower mass can also make the keyhole mode more difficult. Helium argon mixtures are used as a shielding gas for materials such as copper.

Simply stated, **Plasma Arc Welding** (PAW) is a superior variation to TIG welding (GTAW) that encloses the tungsten electrode in a protected environment (Figure 1) and delivers the arc through a cooled copper tip. Enclosing the electrode protects it from contamination, thus substantially extending its life.

The constant stable arc shape of plasma results in consistent welds for eight hours or more of operation as compared to automated TIG welding, where deterioration of the exposed TIG electrode (Figure 2) can result in weld arc variations (Figure 3) in one hour or less of operation. Plasma arc welding uses a pilot arc (Figure 4) to consistently transfer the arc to the work without the repeated use of high frequency current.

**PROTECTED ELECTRODE**

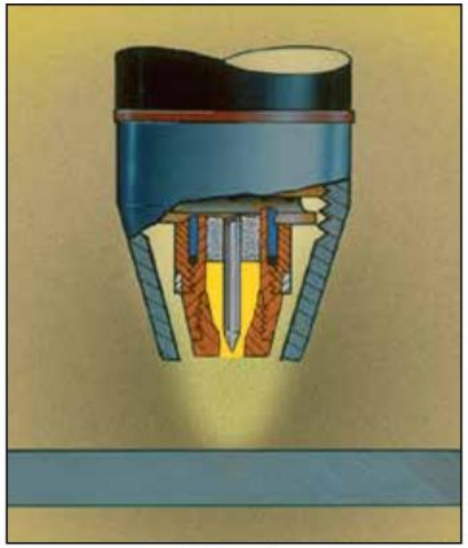


Figure 1

**ELECTRODES**

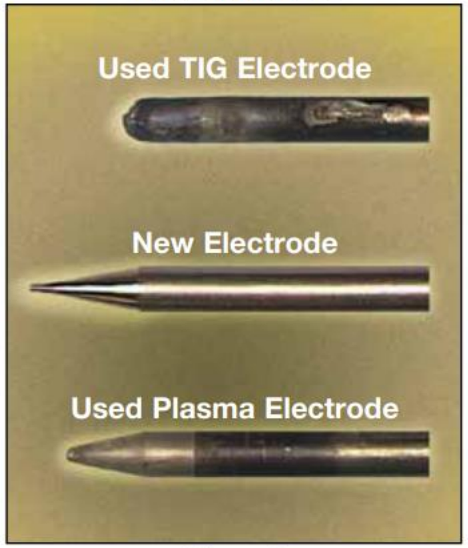



Figure 2

### Pilot Arc

Another outstanding feature of the Plasma arc welding process is the Pilot Arc which provides reliable arc starting and contributes to the repeatability and increased productivity of plasma welding.

The Pilot Arc is a low current DC arc that is sustained in the tip area of the torch to ionize a gas as it passes around the electrode and through the orifice. Arc initiation is provided by the pilot arc that transfers between the tungsten electrode and the tip. It is started by imposing high frequency (from a small high frequency generator or C.D. arc starter inside the control console) on a low DC current for a short duration of time to ionize the gas. Once the pilot arc has been established, the requirements for high frequency are no longer needed. The pilot arc now remains on to reliably assist the starting of the main transferred welding arc from a separate DC power source.

**TIG WELD SAMPLE**

Figure 3

**PILOT ARC**

Figure 4

### Constricted Arc

An orifice (also called a nozzle or a tip) which is inserted into the front end of the torch body provides for the laminar flow of the plasma gas and constriction of the arc. The magnitude of this constriction is normally controlled by three variables ... the orifice diameter, the plasma gas flow rate, and the electrode setback (the distance the electrode is recessed within the tip). The arc will be most constricted when the torch is operated at higher plasma gas flow rates and the electrode placed at maximum setback. This type arc is typically used when trying to achieve keyhole single pass welds requiring maximum penetration, narrower weld beads, minimized heat affected zone, and reduced base material distortion. Keyhole welding is generally used on material thickness ranging from .090" (2.3 mm) to .250" (6.4 mm).

By reducing the electrode setback and plasma gas flow rates, a softer, less constricted arc will occur. This type arc is typically used for the melt-in fusion (non-keyhole) mode and allows for faster travel speeds on reduced base material thickness .010" (.3 mm) to .187" (4.7 mm).

# Advantages of Plasma Arc Welding

Requires less operator skill due to good tolerance of arc to misalignments.

High welding rate.

It has a high penetrating capability (keyhole effect).

High energy is available for welding. It can easily weld hard and rough workpieces.

The distance between the tool and the workpiece does not affect the arc formation.

It has low power consumption for welds of the same size.

The more stable arc produced by the plasma arc welding.

It can be operated at low amperage.

# Disadvantages of Plasma Arc Welding

Expensive equipment.

High distortion and wide as a result of high heat input.

It is a noisy operation so there is a chance of noise pollution.

It has more radiation.

Plasma arc welding is required high skilled labour.

The maintenance cost is high.

# Laser Beam Welding

Light Amplification by Stimulated Emission of Radiation

# Laser Beam Welding

The generation of a laser beam is a three-step process in which steps occur almost instantaneously.

1) Spontaneous emission – The pump source provides energy to the medium, exciting the laser medium atoms so electrons held within the atoms are temporarily elevated to higher energy states. The electrons held in this excited state cannot remain there indefinitely and drop down to a lower energy level. In this process, the electron loses the excess energy gained from the pump energy by emitting a photon. The photons produced by this process, which is called spontaneous emission, are the seed for laser generation.

2) Stimulated emission – The photons emitted by spontaneous emission eventually strike other electrons in the higher energy states. This happens in a very short time due to the speed of light and density of excited atoms. The incoming photon "knocks" the electron from the excited state to a lower energy level, creating another photon. These two photons are coherent, which means they are in phase, of the same wavelength, and traveling in the same direction. This process is known as stimulated emission.

3) Amplification – The photons are emitted in all directions. However, some travel along the laser medium to strike the resonator mirrors to be reflected back through the medium. The resonator reflectors define the preferential amplification direction for stimulated emission. There must be a greater percentage of atoms in the excited state than the lower energy levels for the amplification to occur. This "population inversion" of more atoms in the excited state leads to the necessary conditions for laser generation.

**Figure 2** is a simplified schematic representation of the three stages to laser generation.

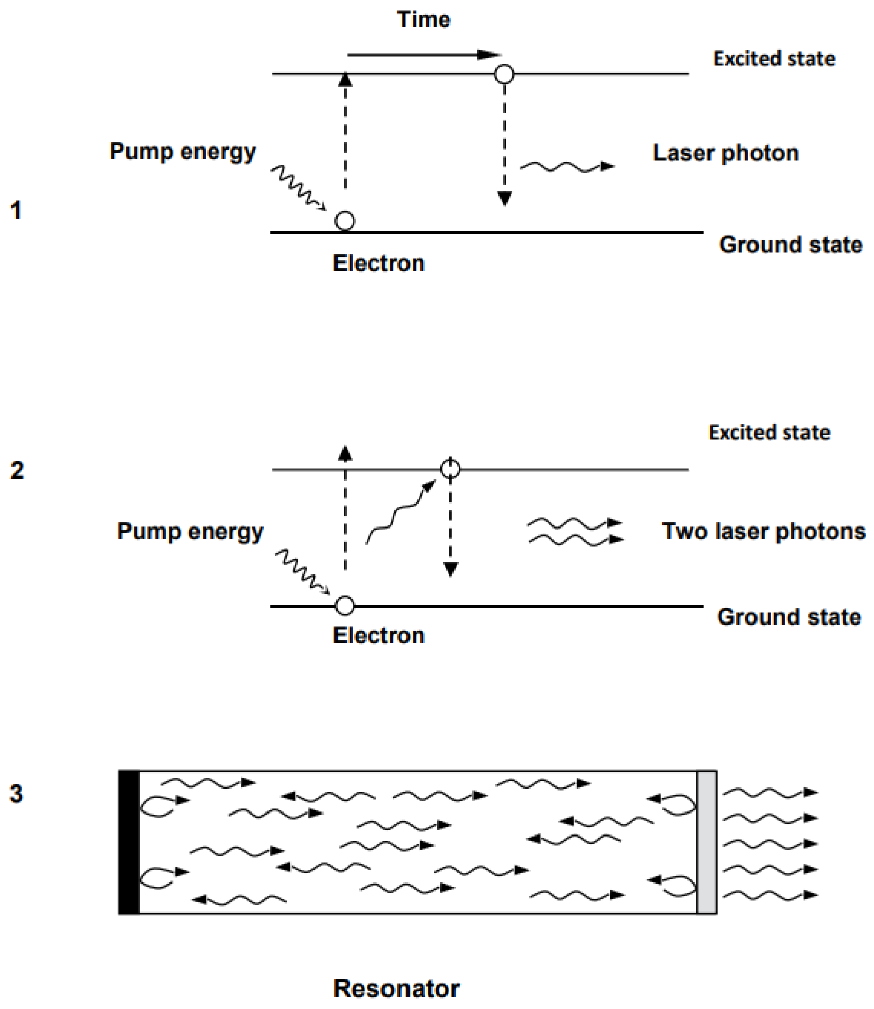



*Figure 2 – Stages to laser generation*

# Welding LASERs

Lasers suitable for welding include pulsed neodymium-doped yttrium aluminum garnet (Nd:YAG), fiber, and diode. Each offers unique features that align to specific applications. The pulsed Nd:YAG laser has by far the largest install base with peak powers and pulse widths designed for micro welding. For example, 25-50 W pulsed Nd:YAG lasers are routinely used for seam welding 0.015-inch thick titanium cases for implantable devices. More recently developed fiber lasers offer excellent flexibility in tailoring weld dimensions and the best penetration per watt performance, which enables high speed seam welding. A 300 W fiber laser can seam weld 0.01-inch thick airbag detonator casings at 2 inches per second, while a 20 W pulsed fiber laser can produce a 0.001-inch diameter spot welds in 0.001-inch thick foil. The architecture of the fiber laser is scalable, with laser powers available at multi kilowatt levels used for penetration welding applications up to and beyond 0.25-inch thickness.

The diode laser is a well-established laser technology that been used for many plastic welding applications, notably in the automotive industry for welding the rear light housing. Welding of plastics with lasers is a current growth area, particularly with the development of laser-friendly plastics and lasers that can weld visually clear plastics. More recently, the diode laser has become available at multi kilowatt levels suited to metal welding.

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 $Nd^{3+}$, 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 Absorption

Laser welding requires that the laser raise the temperature of the material to be welded. The laser must be absorbed by the material to induce a temperature rise. The laser’s power density is around 106 watts per cubic centimeter (watts/$cm^2$).

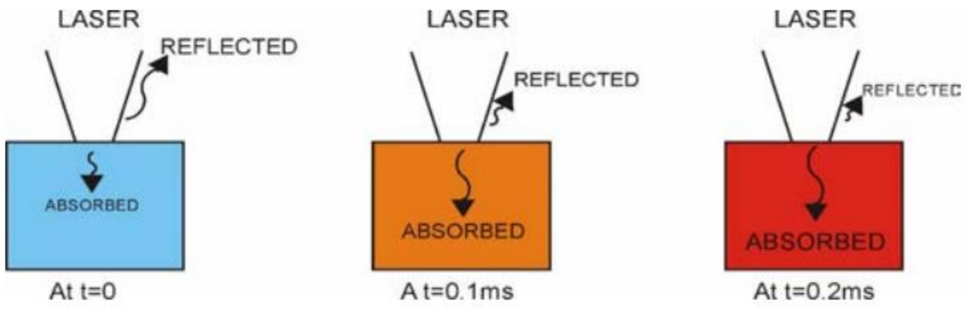



*Figure 10 – Time-based schematic of laser absorption for welding*

# 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.

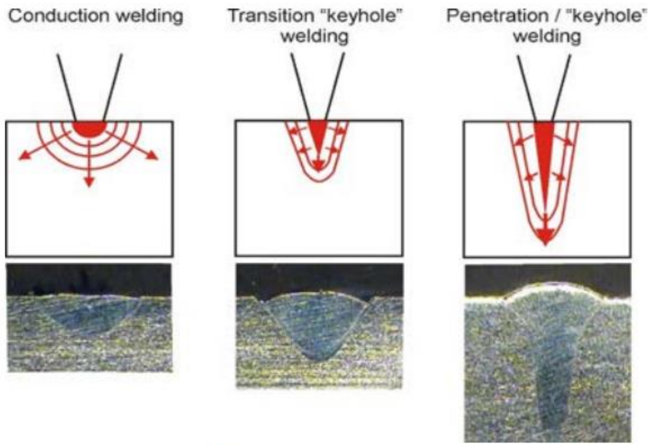



*Figure 11 – Laser mode types*

Conduction mode – Conduction mode welding is performed at low energy density 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 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. Because the optical density of the keyhole is low it acts as a conduit to deliver the laser power into the material.

If conduction welding can be thought of as a point source heating from the surface, then the keyhole can be thought of as a line source heating from within the metal providing a more efficient welding source. In transition mode the time or power density is just sufficient to create but not extend the keyhole deep into the part. Therefore, the welds exhibit shallow penetration with a typical weld aspect ratio (depth/width) of around 1. This mode of welding is used almost exclusively by pulsed Nd:YAG and fiber lasers for many spot and low heat input seam welding applications.

Keyhole or penetration mode – Increasing the peak power density shifts the weld to keyhole mode, which is characterized by deep narrow welds with an aspect ratio greater than 1.5.

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. In 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).

| Material | Comments |
|---|---|
| Aluminum | 1050, 3003 and 6061 to 4047 are OK. Continuous wave welding increases weldability of alloys such as 5052 and 5082. Aluminum alloys should be tested 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, up to 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<br>316 and 316L are OK provided Cr/Ni ratio is greater than 1.7<br>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.<br>400 series require testing for crack sensitivity. |
| Titanium | Good welds |
| Tungsten | Brittle welds |

| Material 1 | Material 2 | Comments |
|---|---|---|
| Aluminum | Cold rolled steel | Can be bonded; brittle intermetallics are created at the interface.<br><br>Fitness for purpose testing essential. |
| Aluminum | Copper | |
| Stainless steel | Nitinol | |
| Stainless steel | Titanium | |
| Stainless steel | Inconel | OK with certain alloys (304 with 600/700), need to watch for cracking.<br><br>When welding, offset into the steel to promote high Cr/Ni ratio in weld metal |
| Stainless steel | Copper | OK |
| Copper | Phosphor bronze | OK |
| Titanium | Aluminum | OK with certain aluminum alloys (1xxx & Ti-6Al-4V) |

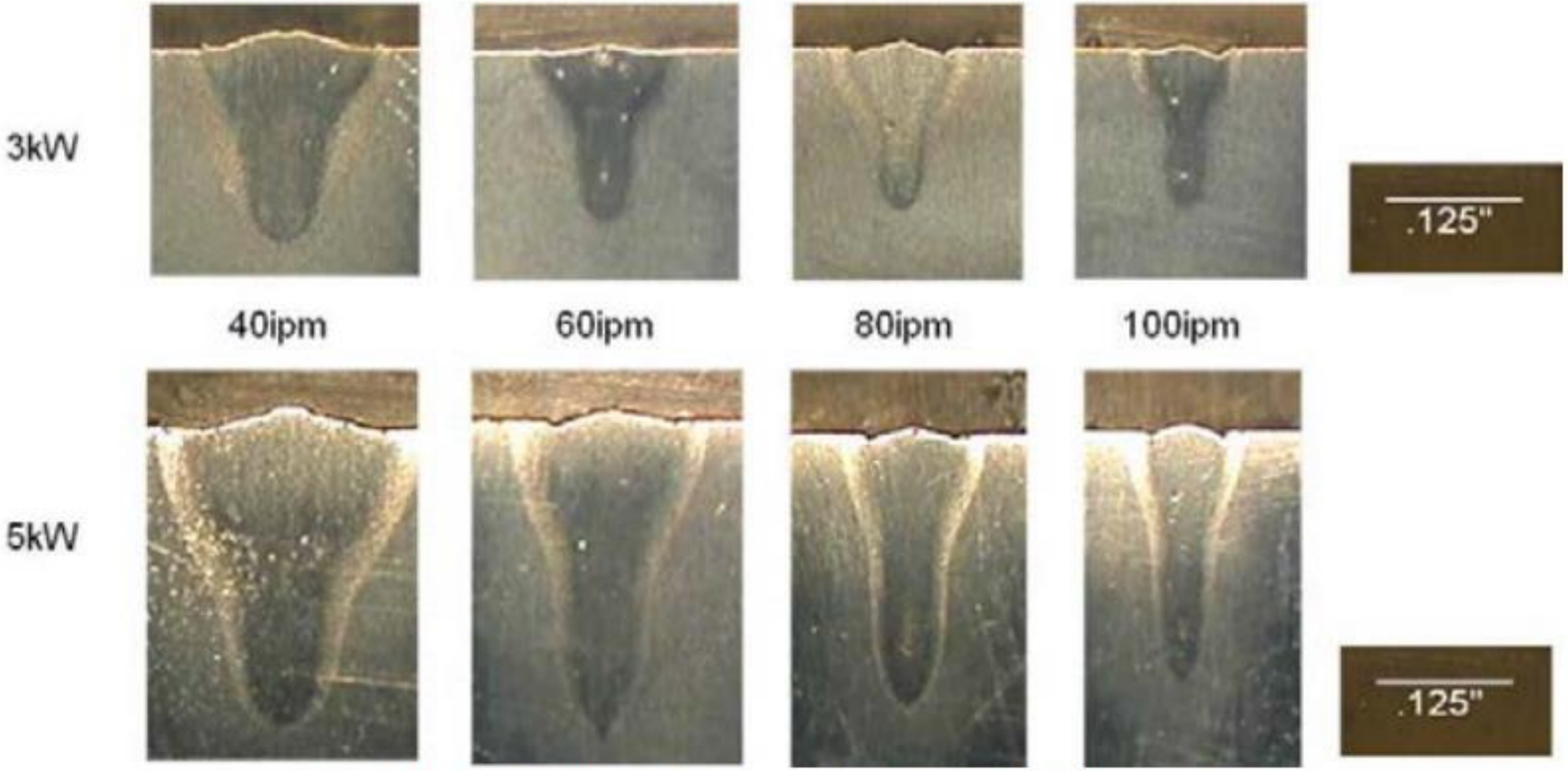


*Figure 44 – Cross sections of penetration and speed for 3 and 5 kW fiber lasers*