Technology advances in plasma cutting of stainless steel

The latest advances in plasma technologies provide exceptional flexibility for cutting stainless steels, ranging from 0.8 to 160mm thickness at high speed and with excellent surface and edge quality.

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Stainless steel accounts for a relatively small percentage of worldwide steel consumption, but it is vitally important to economies, particularly in the energy and food processing markets. There are several technologies for cutting stainless steel; most common are plasma, band saws, water jet for a broad thickness range, and lasers and shears for thinner material. Plasma cutting of stainless steel has a long history, but recent technology advances by Hypertherm have dramatically improved the cut quality and the piercing and cutting thickness ranges achievable.

HISTORICAL PERSPECTIVE
Early plasma systems designed for cutting thick stainless steel used very high amperage and delivered slow cutting speeds compared to current capabilities. An example of this earlier technology was the Hypertherm PAC500 that used nitrogen as the plasma gas and water injection for the shield to cut 75mm material at 380mm/min with 750 amps. To cut 125mm, H35 (35% hydrogen, 65% argon) plasma gas was used with a coaxial flow water skirt at a staggering 1,000 amps with a cut speed of only 150mm/min. Also, in these early systems such as the PAC500, lower amperage cutting was not supported, so additional machines were required for cutting fine features in thinner material.

MODERN CAPABILITIES
Modern capabilities to cut stainless steel with plasma are vastly improved. An expanded range of gas choices and amperages enable a wide array of options to ensure the best process, cutting speeds and desired cut quality are available to meet customer needs. Thickness ranges are: thin 0.8-6 mm, mid-range 6-50 mm and thick 50-160 mm. For example, Hypertherm’s HyPerformance HPR800XD cutting system can cut from 0.8mm up to 160mm, using multiple processes and amperages. Customers can choose the best amperage for a given thickness to determine the ideal balance of productivity and cut quality.

For customers with experience of cutting mild/carbon steel who are expanding into cutting stainless steel, several new challenges and factors must be considered to ensure success. There are three key factors: gas selection, cutting speed and technology requirements for different thicknesses.

Gas selection When cutting mild/carbon steel, oxygen plasma gas and air shield can effectively deliver excellent cut quality across the full range of thicknesses. Successful stainless steel cutting, however, requires different gas selections and consumable technology for different thickness ranges and grades.

Air/air is a common choice for fast cutting speeds and low in cost, but the heavily oxidised black surface finish that is produced often requires labour-intensive secondary operations. Depending on the requirements of the finished piece, there are several additional options to choose from, for example, nitrogen plasma gas and shield (N2/N2) delivers increased cutting speed with a smoother cut surface and fewer oxides formed, but it produces a black cut surface similar to air/air. Top edge rounding and significant (non-vertical) angle on the cut edge may also result.

Customers requiring a more refined cut surface with good colour, sharp top edge with limited angularity and dross, will need to use specialty gases for best results. The modern N2/H2O process is effective for cutting thin and mid-range stainless steel, but the impact of water on dry downdraft tables should be considered before selecting that option.

Cutting with plasma gases containing some hydrogen will produce improved cut edges and with colour similar to the base material. The two most common specialty gases containing hydrogen are H35 (35% hydrogen, 65% argon) and F5 (5% hydrogen, 95% nitrogen).

The pros and cons of different gas options are summarised in Table 1. Figure 1 illustrates cut surfaces of the various options using grade 304L.

Material selection Each steel type will respond differently to plasma cutting so the wide range of stainless steels requires a wide range of cutting processes for best results. For example, 304L is an austenitic stainless steel and the most commonly used grade worldwide. When a plasma, process-engineered for cutting 304L, is applied to another similar austenitic grade, for example 316L, dross and a rough cut edge can result. The
The results of using the 304L process settings for both 5mm 304L and 5mm 316L are illustrated in Figure 2. Note how the 316L cut is inferior and has visible dross. By slightly increasing the cut speed and the shield pressure, the 316L cut was improved to the same cut quality of the 304L.

Additional challenges include molten material viscosity and piercing. While cutting mild steel with O₂/air, the viscosity of the molten material is low so the resulting dross that hardens on the bottom of the plate is very easy to remove and often does not require secondary operations like grinding. With stainless steel dross, the viscosity is much higher so it can be very challenging to remove.

The following five factors influence stainless dross formation:
- **Design of the equipment**
- **Gas type/selection**
- **Gas settings**
- **Cutting speed**
- **Cutting height**

One method of preventing dross is to swirl the shield gas in the opposite direction of the plasma gas. This causes the dross to adhere to the skeleton of the plate instead of the cut piece.

Piercing is particularly challenging because of the dross properties. Slag piles (accumulated dross on the surface of the plate surrounding the pierce hole) build up and present issues for nesting layout and torch movement. This is illustrated in Figure 3. Note the pile height exceeds standard torch cut height. When piercing stainless steel above 50mm, it is common to adjust the torch movement to accommodate the slag piles, or to pierce, stop, then scrape the dross before it hardens and adheres, and then proceed to cutting the part.

### RECENT TECHNOLOGY ADVANCEMENTS

**HDI (HyDefinition inox)** The best possible plasma cut quality on carbon steel has been achieved with the HyDefinition vented nozzle process. This provides higher current densities made possible through the use of vented nozzle technology that delivers sharper top edge quality, smoother cut surfaces with minimal angle deviation and long nozzle life.

For the first time, this same technology is being applied to stainless steel cutting to deliver the best results for thin stainless steel. The higher gas volume with the vented nozzle increases pressure to form a tighter constriction on the plasma arc. This constriction enables use of a smaller nozzle bore and higher energy density. Venting improves the nozzle life by constricting the arc and the higher flows cool the nozzle. A schematic of the nozzle design is shown in Figure 4.

**Gas selection** Advances in mid-range stainless steel cutting returns us to the topic of gas selection. Use of H35 delivers the benefit of a non-oxidised edge with good cut quality and cut edge colour, but from a productivity standpoint, cutting speeds are slow. Nitrogen has the advantage of much faster cutting speeds for increased productivity, but the cut edge is oxidised. Our unique HyPeRformance eXtreme HyDefinition (HPRXD) mechanised plasma power supplies family has an auto-gas console and the ability to mix H35 and N₂ as the plasma gas to significantly improve the cutting speeds while maintaining the desirable silver or gray cut edge. An example is the HPR130XD providing 130 amps. Figure 5
illustrates the effects of gas and thickness on cutting speeds and Figure 6 the resulting edge quality.

Adjusting the proper gas mix for different materials may be required. Too much N2 will result in a gray to black cut surface with likelihood of some dross accumulation. Too much H35 will result in a gold colour on the cut surface and dross build-up.

Patented PowerPierce This technology improves both mild steel and stainless steel cutting across a wide thickness range, and has proven to be the technology that is vital to extending the piercing and cutting thickness range far beyond what was previously attainable.

Key benefits of this technology are that it:
- significantly reduces dross adhesion
- reduces O-ring melting
- reduces interference with initial height sensing
- reduces clogging of the shield’s vent hole, and
- reduces orifice melting

The key technology is the liquid cooled shield which repels molten material that can adhere to the torch shield during piercing. This technology keeps the torch cooler, which prevents the molten metal from sticking to it so minimising torch damage and metal adhering onto torch during piercing. Molten metal meeting a hot metal surface bonds immediately and efficiently. By cooling the shield, the molten metal that contacts the shield does not bond easily because the molten metal reacts to the cooler surface temperature and begins to solidify without adhering to the PowerPierce shield surface.

Figure 7 shows the coolant flow and demonstrates how this torch and consumable design brings the coolant into direct contact with the shield, thus reducing the damaging effects of molten material expelled during the piercing process (the blue line within the red circle shows the coolant flow path). Hypertherm utilises two pierce ratings for each of the HPR400XD and HPR800XD machines. These have different power sources (400 amps and 800 amps, respectively), and have a new innovative controlled motion to deliver maximum pierce thickness. The production piercing rating test criteria is the ability to successfully stationary pierce (up and down motion) a given thickness 300 times with one set of consumables. If a system can only pierce a certain thickness, say only 250 times, the thickness is lowered until the complete 300 pierce test is successful.
The torch then begins to drop while at the same time table motion slows until the pierce is achieved and normal cutting speed ensues. The stages are also illustrated in Figure 9.

**Dogleg piercing and cutting** The extended thickness capability for piercing and cutting stainless steel brings with it a new challenge due to the physics of plasma. The arc lags behind the torch at around 15 degrees, so when cutting a thick part in a nest, a small tab may result that causes parts to stick to the nest and internal features that have pronounced dings, bumps or nubs. A new ‘dogleg’ technique developed by Hypertherm efficiently addresses this challenge while minimising any additional plate consumption.

The method takes advantage of this lagging arc by focusing it onto the tab section of the cut. At the point where the leading kerf edge breaks into the lead-in edge (and before the voltage reaches the critical value of the transformer), the cut path changes direction into an acute angle (60 degrees works well) toward the skeleton. This allows the arc to transfer to the skeleton material, which reduces the voltage while driving the molten material down towards the tab and subsequently melting it off.

**SUMMARY**

Plasma cutting can be used productively to cut stainless steel across a very wide thickness range. Proper gas and current selection results in clean, high quality cuts and new technologies have improved the outcomes on thin, mid-range and thick stainless steel. The advantages of plasma’s use of thermal energy and high velocity gas to melt and remove material from the cut surface include fast cut speeds compared to band saws and waterjet systems, thicker cutting capability than lasers and the flexibility to switch quickly from cutting 160mm to cutting fine features in thin stainless, or even aluminum and mild steel. MS

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The new maximum pierce rating utilises a tightly controlled moving pierce technique to extend the HPR400XD production pierce rating from 45mm to 75mm and the HPR800XD production pierce rating from an industry leading 75mm to an unprecedented 100mm. Testing for the new maximum pierce delivered 50 pierces at 400 amps and 25 pierces at 800 amps.

**Moving pierce processes** While so-called moving or flying pierce processes have been practised for many years, the new process illustrated in Figure 8 provides the advantage of minimal pierce length – usually only about as long as the material is thick. It essentially involves controlling table motion with torch height, to create a trough that enables the slag to exit the pierce hole and direct it away from the torch front-end. The pierce is initiated as high above the plate as the power supply will allow without losing the arc, and then traversing at a relatively high (gouging) speed to create the trough. The torch then begins to drop while at the same time table motion slows until the pierce is achieved and normal cutting speed ensues. The stages are also illustrated in Figure 9.

![Fig 7 Nozzle with liquid-cooled shield technology](image)

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![Fig 8 Thick piercing capability](image)

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![Fig 9 Moving pierce processes](image)

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