Plasma welding – State of the Art

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Principle of the process, different plasma-processes, the plasma process, comparison with TIG-welding, welding equipment, typical applications, alternative processes, ongoing research-project, SLV-Munich.

1. Introduction

Plasma welding can be seen as a further development of TIG-welding. The main difference is the arc constricted by a water cooled copper nozzle.

This constricted arc is named "Plasma Arc". This comparatively very hot arc has a very high power density which offers a deep weld penetration and/or high welding speed.

A safe arc ignition is reached with a so-called "Pilot Arc" started with high voltage and burning between the tungsten electrode and the copper nozzle.

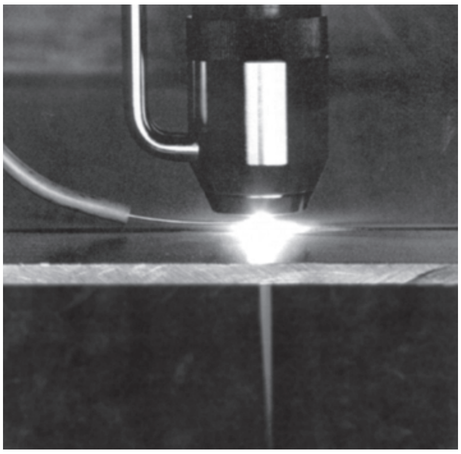

Figure 1. Plasma torch

Plasma welding is suitable to weld almost all of the weldable materials and specially used for joining of mild and alloyed steels and increasing aluminium materials.

Plasma welding is usually conducted mechanized producing long weld seams as butt-joints without weld preparation and sheet thickness between 0.1 to about 10.00 mm. Filler metal is only frequently added.

The so-called plasma gas is usually Argon (Ar) with a purity of 4.6 (99.996 Vol. %).

2. Plasma Processes

2.1. Overview

Plasma welding, plasma cutting and plasma spraying processes are relatively new. In 1955 UCC (Union Carbide Corporation) invented a plasma torch for plasma cutting of aluminium. A short time later this torch was taken over by the Linde company (USA). The reason for the inventing the plasma process was the increased use of chromium nickel steel and aluminium materials. Both material groups were not to be cut by autogenous flame cutting. For this plasma torches have been developed to cut and join these materials. The difference between a plasma arc and a free burning arc (e.g. a TIG arc) is that the plasma arc is constricted by a good water-cooled copper nozzle. This constricted arc (the so called plasma arc) has very specific properties.

Figure 1 shows a plasma torch with the arc penetrating a work piece

Usually the arc burns between a non-melting Wolfram electrode and the work piece. Inert gas (argon) flows through the constricting nozzle and is strongly heated up and turns electrical conduction in the arc (Plasma effect). Based on the shape of the plasma nozzle and the plasma gas amount it is mostly possible to perfectly adapt the arc to the welding task.

In Table 1 the actually in practical application used plasma processes are listed.

Different plasma processes, applications and parameters are given in Table 2.

2.2. The Plasma Process

Different types of electrical circuits are pointed out in Figure 2.

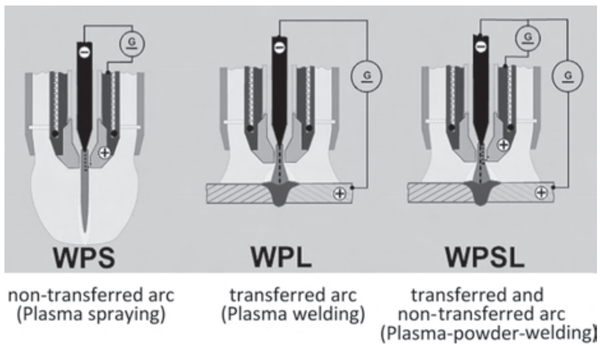

Figure 2. Types of electrical circuits for plasma processes

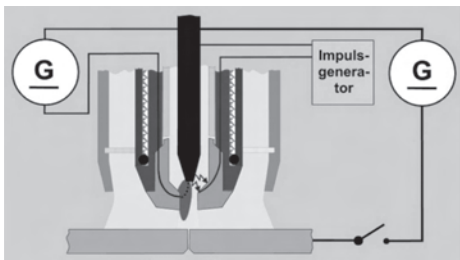

Figure 3. Process ignition

Different methods can be used to start a TIG arc. It can be high voltage, short circuit or so called "lift arc". In plasma welding a pilot arc starts the main arc, as shown in Figure 3.

Table 1. Practical applications that used plasma processes

Plasma process		
Joining	Surfacing	Cutting
Micro-plasma welding Plasma welding Plasma welding with keyhole Reverse polarity plasma arc welding Plasma welding with AC Plasma MIG welding	Plasma surfacing process Plasma hot wire surfacing process Plasma MIG surfacing process Plasma spraying	Plasma cutting with Ar, H_2, N_2 or O_2 Plasma cutting with air Plasma cutting underwater Plasma cutting with water injection

Table 2. Plasma processes - applications and parameters

Process	Application	Amperage	Base material	Comment
Micro plasma welding	Connection of foils, plates, tubes, wires etc. of 0.1 -1 mm	0.2 - 20 A DC electrode with – polarity	CrNi-steel, Ni-alloy, dead construction steel special material	Manual and mechanised welding at very thin parts, very precise clamp-ing device necessary, mostly with-out filler metal
Plasma welding	Connecting parts up to a thickness of > 3mm	> 20 - 200 A DC, electrode with – polarity	See above	Manual and mechanised welding possible with or without filler metal
Plasma welding with keyhole effect	Connecting plates, tubes etc. of 3 - 9 mm	100 - > 300 A AC or DC	See above	Only mechanised welding, good root formation due to keyhole effect, good seam preparation pos-sible with and without filler metal.
Plasma welding of Al-materials	Connection of parts with a thickness of 0,5 - > 10 mm	20 - >200A DC, + poled electrode or AC	Aluminium and Al alloys	Regular plasma and keyhole tech-nique possible
Plasma MIG welding	Connection of parts with a thickness of 3 - > 10 mm	>300A DC	Mainly Al and Al alloys	Only mechanised welding Very powerful
Plasma hot wire welding	Large-surface overlay of corrosion resisting and long wearing layers	Plasma: 450 A Hot wire: 150 - 400 A	CrNi steel, construction steel, Cu, Cu-alloys, Ni, Ni-alloys. other materials, hard surfaces	Mainly for large parts i.e, reactor pressure vessels
Plasma powder welding	Surfacing of hard and cor-rosion resisting layers at small parts	Up to 300 A	High alloyed materials, carbides. stellites in powder state	Mechanised process, very low dilu-tion with the base material
Plasma spraying	Surfacing of thin layers	Up to 500 A	Many metal alloys metal oxides. ceramic materials	With good preparation very good adhesion of spatter layers
Plasma cutting	Cutting electricity con-ducting materials up to a thickness of 100 mm	100 - >500A	CrNi-steel, aluminium, Al-alloys, construction steel, other materials	Torch mostly manually led, high cutting velocity, good cut edges

DCSP-Direct Current Straight Polarity

For most of the applications the electrode is negative poled (cathode). The work piece is positive poled (anode), as in the case of TIG welding. Since at the torch is covered by the nozzle, a pilot arc is needed in order to surely ignite the main arc from the electrode to the work piece. The pilot arc is between electrode and nozzle ignited with high voltage impulses (amperage about 10 A). This pilot arc ionizes the plasma gas depositing of the nozzle. After turning on the welding circuit the arc transfers from the electrode through the constricting nozzle to the work piece.

A particular method to weld thicker steel plates the so called “keyhole technique”, as shown in Figure 4.

Is the plasma gas amount increased when plasma welding with amperage above 100 A the depositing plasma jet is able to push aside the welding good and hole the plate. If the torch is moved forward, after holing, the welding good flows together behind the so called keyhole.

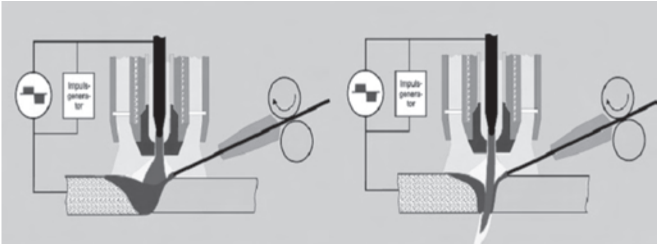
a) plasma welding without keyhole
b) plasma welding with kwyhole

Figure 4. Keyhole technique

Advantages of the keyhole technique:
- Secure through-welding
- Even weld root
- Square butts at CrNi steel from 3-9 mm with low amounts of filler wire possible
- Square butts at construction steel from 4-6 mm with low amounts of filler wire possible
- Square butts at Al alloys from 5-7 mm with low amounts of filler wire possible

Comment: At thick plates the seam root can be welded with the plasma keyhole process. Fiii runs are welded with a different process, Due to the stronger root formation at aluminium alloys a filler wire is necessary during keyhole welding or welding of an additional layers useful.
- Low heat input
- Low distortion
- Very high welding velocities possible
- High seam quality

A weldment on corrosion resistant steel with keyhole effect is shown in Figure 5.

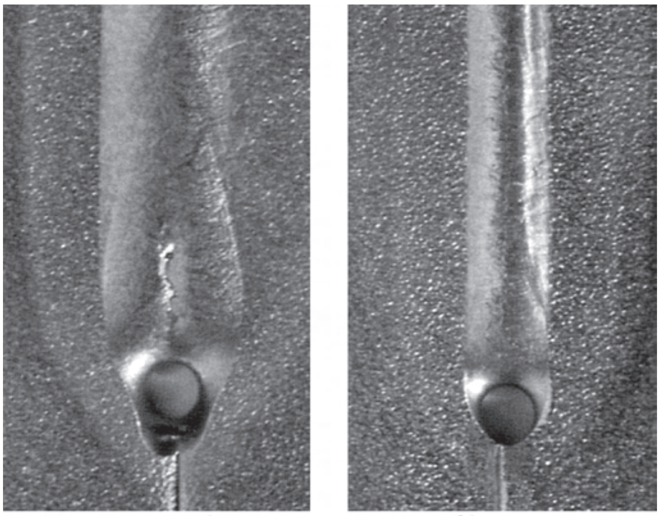
a) b)

Figure 5. Welded joint using keyhole effect.
a) Top view of the weldment; b) Root area of the weldment

2.3. Welding data

The most important set up data br plasma welding are:
1. Welding amperage according to welding task
2. Plasma nozzle drilling diameter
3. Plasma gas (always Argon), amount of plasma (minimum amount is to consider)
4. Shielding gas:
   - for construction steel - 100 % argon (argon 4.6)
   - for CrNi steel - 100 % argon or. Ar-H_2-mixtures with for example 6.5 % H_2,
   - for Ti, Zr - high-purity argon 4.8
   - for Al, Al alloys - 100 % Ar, 100 % He or Ar-He-mixtures with 30-70 % He

Operating areas for Plasma Welding are displayed in Table 3.

3. Comparison Plasma / TIG-Welding

The constricted arc has a comparatively higher temperature and a higher power density. This results in some advantages in comparison to free burning arcs. This will be explained by comparing TIG- and Plasma Welding.

In Figure 6 on can see the temperature distribution of a free burning TIG-arc compared to the temperatures of a Plasma arc.

Figure 7 shows the power densities of different welding processes.

Table 3. Operating areas for plasma welding

Amperage [A]	Joining by welding	
	Micro plasma welding	Plasma and plasma keyhole welding
0.1÷10	foils - 0.05÷0.2 mm	-
1÷20	thin plate - 0.2÷0.5 mm	-
5÷40	thin plate - 0.5÷1 mm	-
40÷100	thin plate - 1÷2 mm	plasma - 0.5÷1.5 mm
100÷200	-	plasma - 1.5÷3 mm
100÷350	-	plasma keyhole - 3÷10 mm

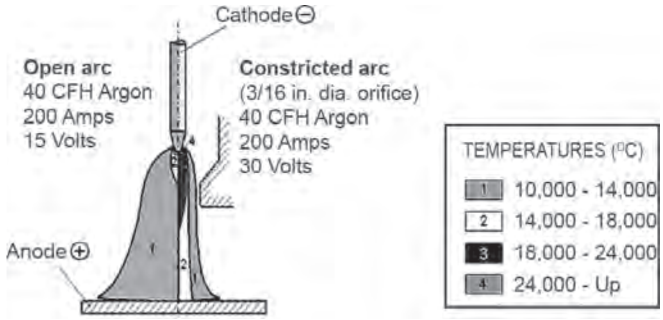

Figure 6. Temperature distribution

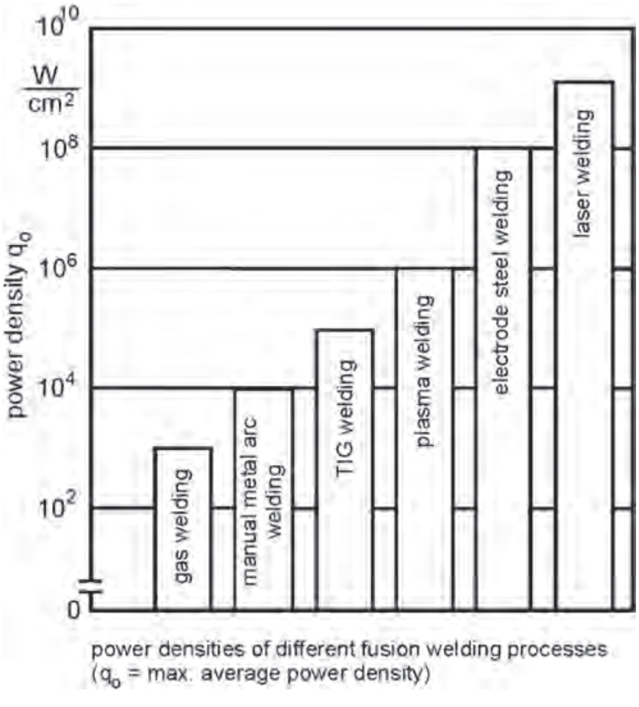

Figure 7. Power densities of different welding processes

Because of the specific characteristics of a plasma arc, especially when using the keyhole effect the maximum welding speed in case of plasma welding is remarkable higher than TIG-welding, as shown in Figure 8.

Advantages of plasma welding compared to TIG welding
- Concentrated arc, insensitive against change of arc length
- Flashlight effect
- Stable arc, also at very low amperages
- High welding speed possible

• Low heat input
• Favourable seam shape

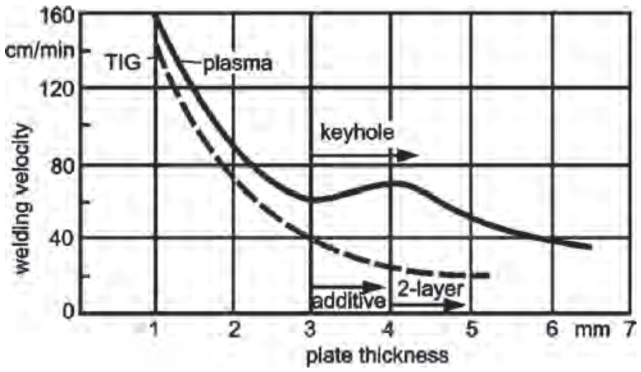

Figure 8. Welding velocity

Disadvantages of the plasma process
• Good training of students necessary
• Machines and spare parts expensive

4. Welding Equipment

4.1. Plasma Torch

Available on the market are manual and mechanised torches. Since years torches with negative poled electrode are used. They achieve very good electrode life.

Good torches which also enable to welding with a positive poled electrode (electrode stress up to 8 times higher) are only produced by a few companies.

The manual welding torches are similar to the TIG ones. The handle tube is equipped with an offset torch head which nas a larger diameter at plasma torches compared to TIG torches. The tungsten electrode has to be centred exactly in order to have the same radial distance between nozzle and electrode. The axial distance between electrode and nozzle is determined with set up aids and should be kept at ±0.1 mm.

At TIG welding the electrode burns off if it is overstressed (too much current). The damage is relatively low. Is, in contrast, a plasma torch overstressed a greater damage occurs - nozzle fused, electrode defect - even the torch might be damaged. Therefore, the indicated standard values concerning the max. amperage have to be strictly observed.

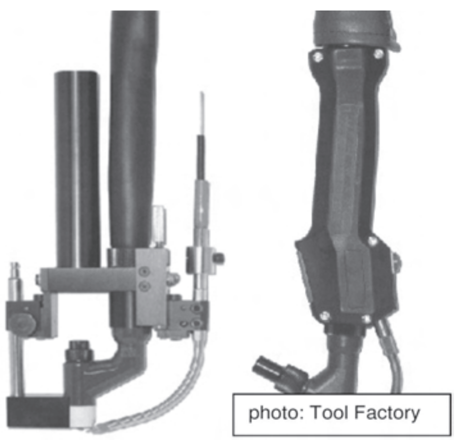

Figure 9. Plasma torch for mechanized welding

A plasma torch for mechanized welding shows Figure 9, on the left side, and on the right side a torch for manual welding.

4.2 Plasma Power Source

The power supplies are constant current power supplies (AC or DC) that means that a change in arc length effects a considerable change in the arc voltage and no or just a low change in the welding current.

The welding current regulation such as in the case of TIG power supplies is effected by a scattering kernel, a transductor, a thyristor or a transistor.

The no-load voltage of this power supply is mostly set up to the highest limit permitted (VDE) in order to achieve good ignition characteristics.

Dependant on the application purpose the power supply can similar to TIG welding be equipped with special features such as current increase, pulsed welding current, current decrease etc.

The Figure 10 shows a modern power source for plasma welding.

Figure 10. Power source for plasma welding

For example:
- Open circuit voltage 80 V
- Weld current 100% duty circle 250 A
- Pilot current 100% duty circle 20 A
- Setting range plasma gas 0.5-2.5 l/min
- Setting range shielding gas 2.0-20 l/min

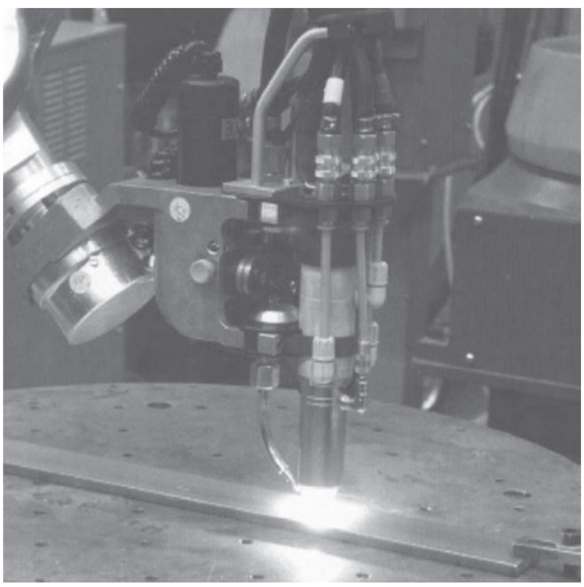

Figure 11. Plasma torch

A plasma torch mean while welding shows Figure 11 and a complete Plasma Welding unit is given in Figure 12.

In figures 13 to 18 are presented typical applications for plasma welding process.

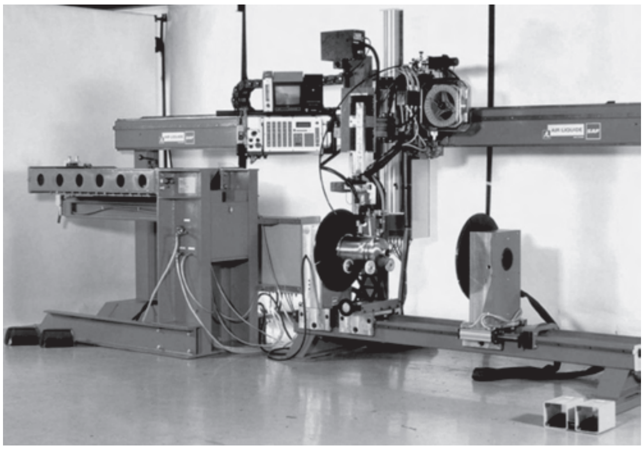

Figure 12. Plasma welding unit

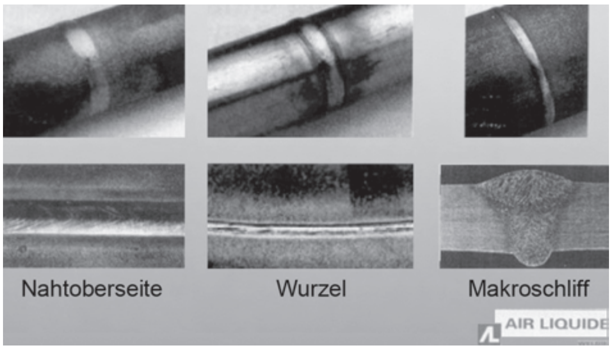

Figure 13. Plasma welding of tubes, mild steel

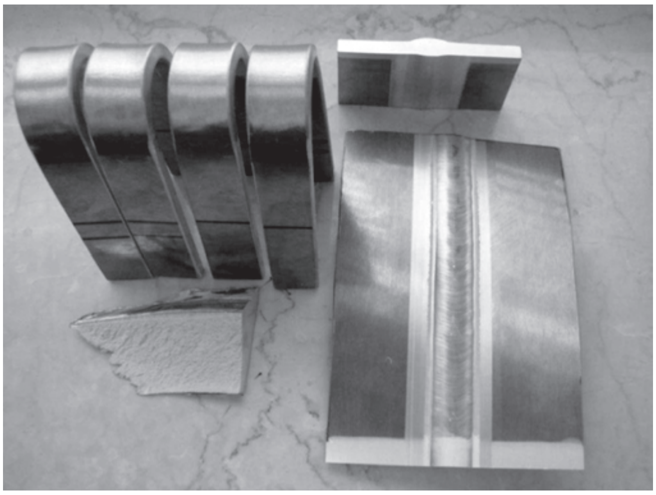

Figure 14. Plasma welding of aluminium 5083, sheet thickness 6 mm, DC, + polarity

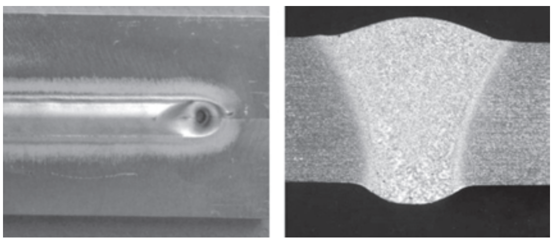

Figure 15. Plasma welding of aluminium with keyhole and AC, shielding gas Ar with 75 % He (SLV Munich)

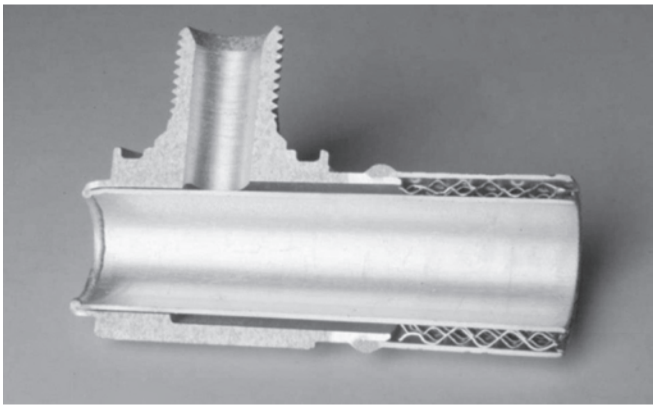

Figure 16. Plasma welding of thin walled parts (Al)

Figure 17. Plasma welded container, stainless steel

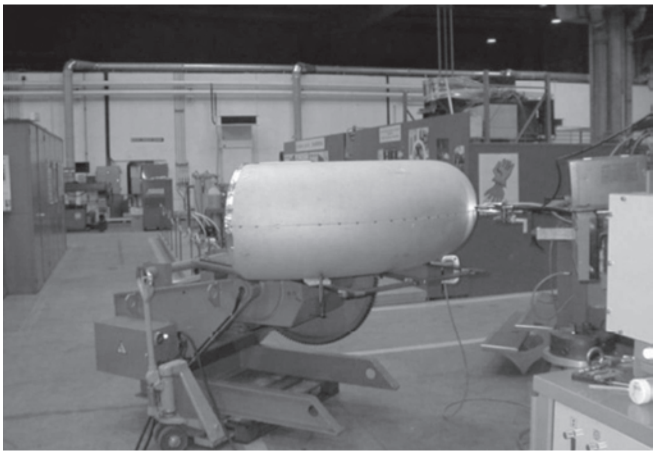

Figure 18. Plasma welding of pipe elbows, stainless steel

5. Plasma Processes – Variations

5.1. Micro Plasma Welding

The constricted plasma arc still exists at very low amperage rates and allows welding of very small parts.

Figure 19 shows a micro plasma torch and Figure 20 shows a wire mesh welded with micro plasma welding.

5.2. Plasma Powder Surfacing

With this process very hard surfaces (stellite) can be produced. The filler metal is powder because wires of these type a material cannot be generated.

Figure 21 shows a section of a work piece with a surface beat produced with the plasma powder surfacing process (SLV Halle).

Figure 19. Micro-plasma torch

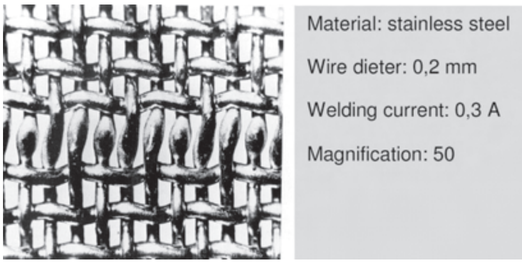

Figure 20. Wire mesh welded with micro plasma welding

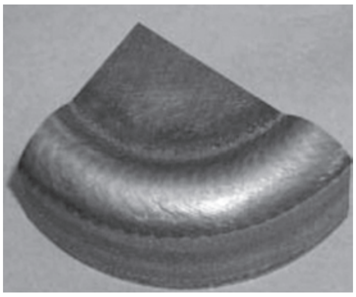

Figure 21. Surface beat produced with the plasma powder surfacing process

5.3. Plasma Hotwire Surfacing

This process has been developed to create large area surfacings. The deposition rate is very high. Heat soure and filler are seperated. The process is not very often used.

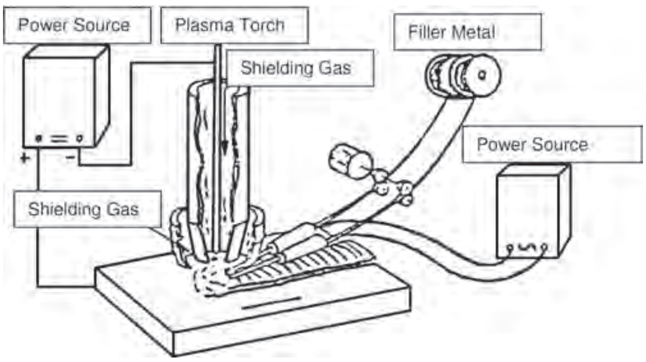

Figure 22. Schematically design of Plasma Hotwire Process

In Figure 22 the schematically design of the Plasma Hotwire Process is shown.

5.4. Plasma Soldering

The heat source and the filler are separated and this enables good bridge ability between two work pieces. Figure 23 shows the manually Plasma soldering at a BMW car body and Figure 24 a Solder joint without melting base metal.

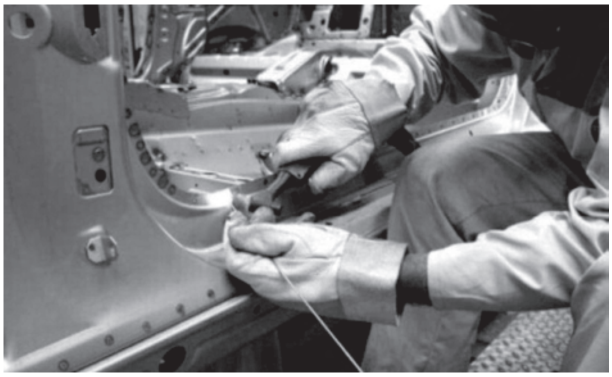

Figure 23. Manually plasma soldering (photo BMW Binzel)

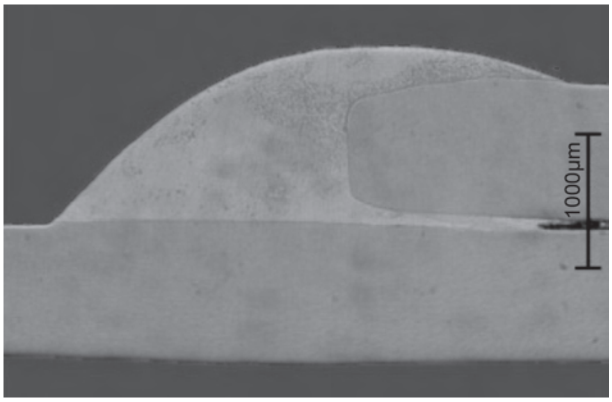

Figure 24. Solder joint without melting base metal

5.5. Plasma Spot-Welding

This process is comparable to TIG Spot-Welding. The process is particularly used when joining work pieces with differing sheet thicknesses and one sided accessibility.

Figure 25. Plasma Spot-Welding Torch

Figure 25 (left side) shows a Plasma Spot-Welding Torch and **F**igure 26 shows a vine tank, stainless steel (photo: SBI).

Figure 27 show a micro section of a weldment mage by Plasma Spot-Welding, stainless steel

Figure 26. Vine tank

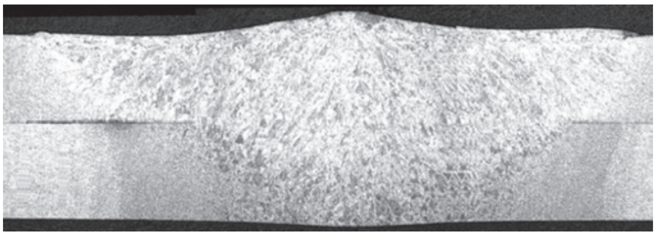

Figure 27. Micro section intro plasma spot welding joint

6. Actual Research Project of SLV Munich

The SLV Munich is running research and development project privately funded by companies and via public funds.

The main fields are such as friction welding, stud welding, laser welding, and shielding gas welding.

In recent years the SLV Munich is undertaking research working on plasma welding, particularly plasma welding of aluminum materials using alternating current as well as direct current, electrode at plus polarity.

Plasma hybrid welding – Plasma GMAW (Gas Metal Arc Welding) –welding is the at present running research project.

In Figure 28 the principle of the torch is schematically shown.

The main target of the combination of the plasma- and the GMAW-processes in the space of one torch is to combine the advantages of both processes and to reach a high welding speed at work pieces up to a thickness of about 20 mm without weld preparation.

Because of the different polarity of the plasma- and the MSG-arc the first part of the running research project was the improvement of the torch by using magnetic fields to reduce the mutual influence of the two arcs because of their own magnetic fields. An important tool is the simulation of the two arcs and to highlight the influence of external magnetic fields to regulate the movement of the arc.

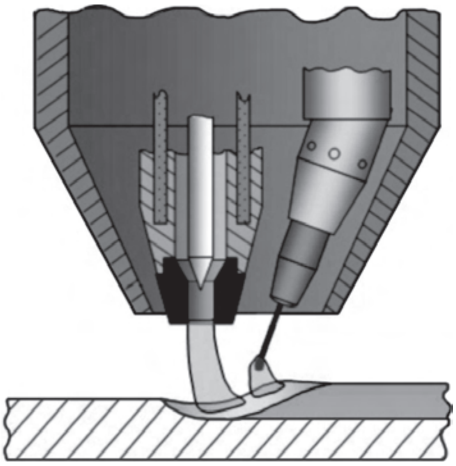

Figure 28. Principle of the torch for Plasma GMAW welding

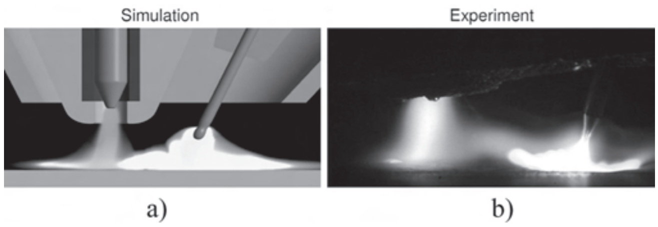

Figure 29. Comparison between the simulation of the two arcs (a) and the real situation (b).

In Figure 29 a comparison between the simulation of the two arcs (left side) and the real situation shown via high speed short-takes demonstrates the very good compliance simulation to reality.

The application of plasma welding shows an increasing tendency and will certainly step up in the near future.