Efficient
Arc Welding Methods

Edition 2011

Chapter 5: Multiple heat sources hybrid welding

5 多热源复合焊接

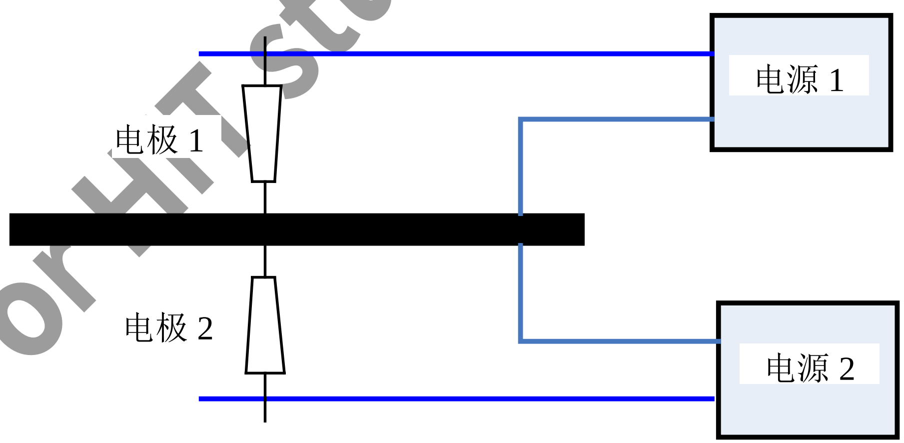
双面双弧焊接

- 双面双弧焊(**Double-sided arc welding， DSAW)**的含义是在焊接接头的正反两面各采用一把焊枪，同时同方向进行焊接。
- 优点：
  - 提高焊接熔深，增加焊缝深宽比。在**DSAW**中，由于两把对立焊枪作用而诱发的磁场使等离子电弧高度集中，其焊接熔深得到了显著提高。
  - 降低焊接变形。**DSAW**技术的特点是被两把焊枪加热的工件两面的热分布是对称的，能够显著减小焊缝的扭变变形倾向。
  - 提高焊缝质量。**DSAW**能防止焊接的咬边，并可减少焊缝的凝固裂纹敏感性。**DSAW**的焊接区组织凝固后倾向形成等轴晶粒，具有良好的机械性能。
- 双面双弧焊接适于厚板的焊接

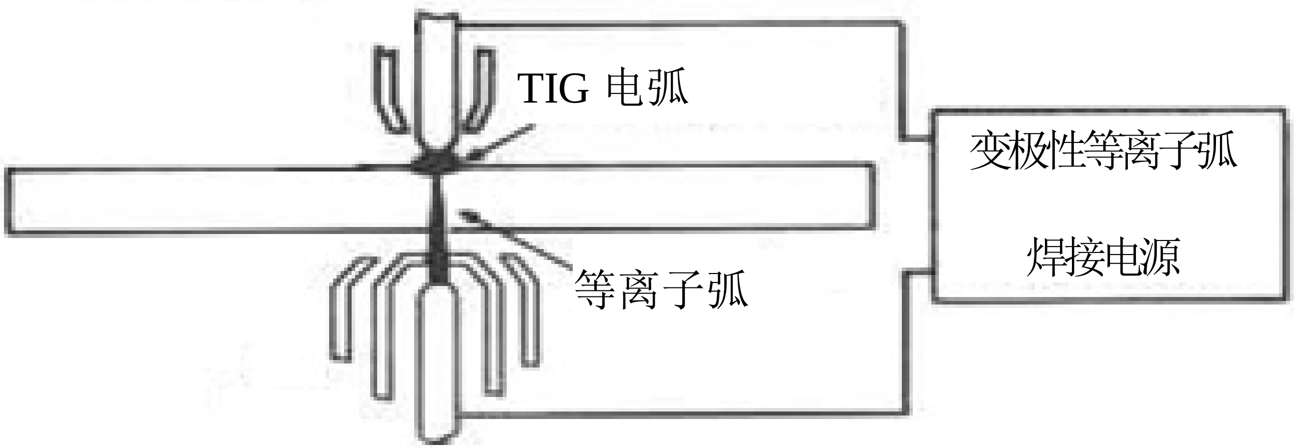
双面双弧焊分类

- 根据焊道顺序的不同分为打底焊、填充焊和盖面焊。
  - 打底焊中双面双弧之间形成共同的熔池，相互作用强烈，由于两侧电弧之间可以实现对于对侧电弧的背面气体保护，有利于焊接接头质量的提高，实现无清根的打底焊接。
  - 对于填充焊和盖面焊的双面双弧焊，由于双弧之间不形成共同的熔池，相互之间主要的是热作用。此时，焊接热输入应该是双弧共同作用下形成的。在两电弧错位的情况下，前后电弧相互之间相当于预热和后热的作用，有利于焊接组织的改善。

- 双电源型
  - 双电源型指的是在焊接过程中，两把焊枪分别由两台焊接电源提供动力，在焊缝的两侧焊接过程独立进行。
  - 源为等离子电源、氩弧焊电源或**GMA**焊电源，两侧的电源可以相同或不同。
  - 焊接过程中两把焊枪可保持一前一后的错位位置状态进行同步焊接；或两个焊枪在同一位置进行同步焊接。



- 单电源型
  - 单电源型双面双弧焊接是焊缝两侧的焊枪由一台焊接电源提供动力，即将两个焊枪分别连接于同一台焊接电源的两极，待焊工件不再是电极。



应用

- 双电源型双面焊接工艺方法已经大量应用于工厂的实际生产中。
  - 采用双面GTA双枪对称焊接不锈钢、铝合金等板厚小于**10mm** 以下的薄壁容器， GTA焊枪在焊缝的正反面同时同步焊接，焊接时同时起弧，同时熄弧，双面熔化。具有速度快、质量高、节能高效的特点。
  - 利用两把焊枪的热量建立一个基本熔池进行焊接,可一次性焊接完毕。该工艺解决了焊缝背面保护问题，省掉了加工坡口的工序，而且减小了焊接热影响区和输入热量，同时有效地控制了焊接变形。

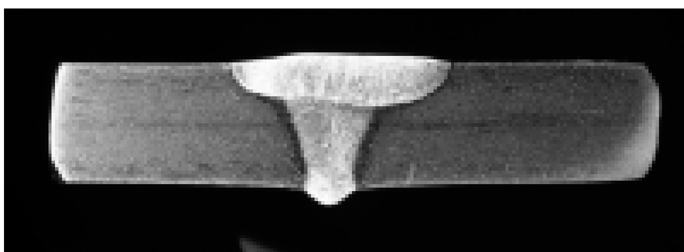
日本的IHI Kure和SHI Yokosuku船厂对多个T型接头厚板结构用双电源双面双弧焊

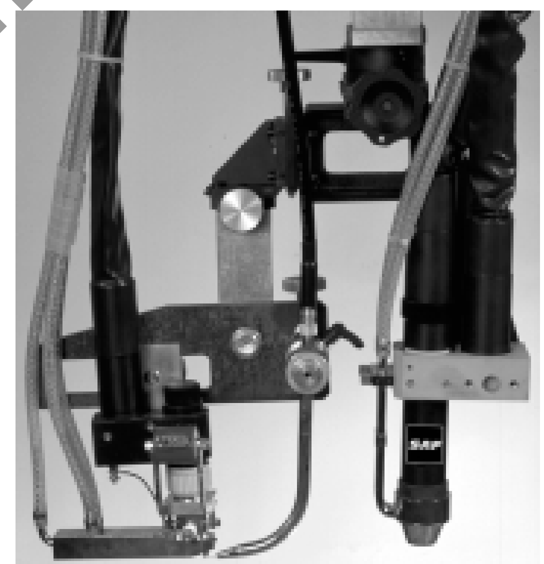
PAW与TIG复合焊接

图片和设备资料由法国SAF公司提供

PAW+TIG

- **The association of PLASMA and TIG processes in automatic welding preserves the quality characteristics specific to PLASMA (compactness and penetration), a gain in speed of %, with the TIG process ensuring smoothing and quality with a flawless appearance.**





Comparison of welding speeds

THICKNESS mm.	PLASMA	PLASMA + TIG
	Welding speed (cm/min.)	
3	50	65
4	35 - 40	50 - 60
5	25 - 30	40
8	15 - 20	25

PAW+TIG

- **For the PLASMA + TIG process, a TIG torch as well as a cold wire contribution device are positioned at around mm behind the plasma torch.**
- 等离子弧用于熔化整个接头，**TIG**焊接带有摆动和送丝，用来盖面。
- **plasma + TIG** 方法通常应用在焊缝长度 **> 3000 mm**的场合**,** 筒体直径大于**2 200 mm.**

- 单道焊接过程**,** 降低填充金属量，高速焊接，低变形
- 热影响区窄，高质量，焊缝外观好，降低坡口准备时间。

PAW+TIG

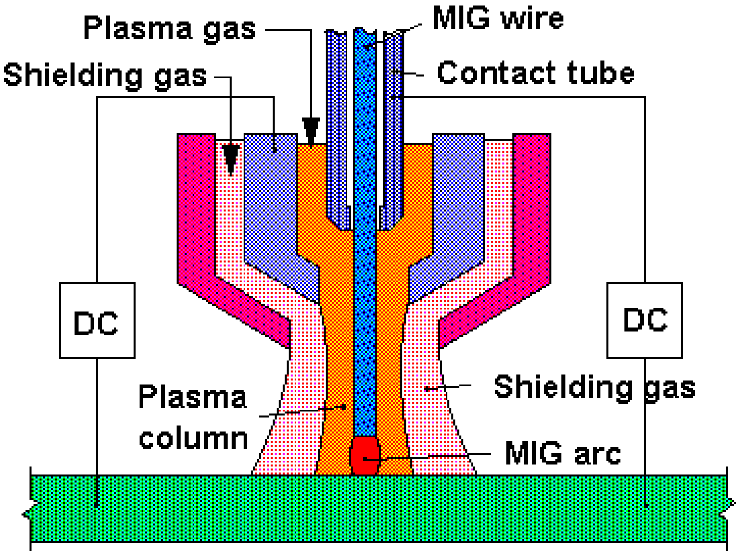
- 应用

PAW与MIG复合焊接

(熔化极等离子)

原理

- 等离子弧与MIG弧同轴并且在一把焊枪内燃烧，焊丝的底端、熔滴和MIG电弧都包围在炽热的等离子弧内部。
- 焊丝不仅被流过焊丝的电流和MIG电弧加热，而且还被周围的等离子弧加热。
- 在焊丝电流产生的磁场作用下，等离子弧可以进一步被压缩，熔滴过渡稳定，没有飞溅发生。



优点

- **Plasma-MIG**焊枪由于加入了压缩喷嘴，导致熔化极焊丝的干伸长较常规**MIG**焊大，此外压缩的等离子弧对焊丝和工件有加热作用，使得**Plasma-MIG**焊接工艺具有以下优点：
  - 熔敷速度高，**1.6mm**低碳钢焊丝在大电流情况下可以达到**500g/min**，对于中、厚壁开坡口的工件，可以实现单道一次性填充，大大提高焊接效率
  - 焊接电弧稳定性和熔滴过渡可控性提高，焊接过程无飞溅
  - 可以实现薄板的高速焊，是常规**MIG**焊效率的几倍

普通MIG

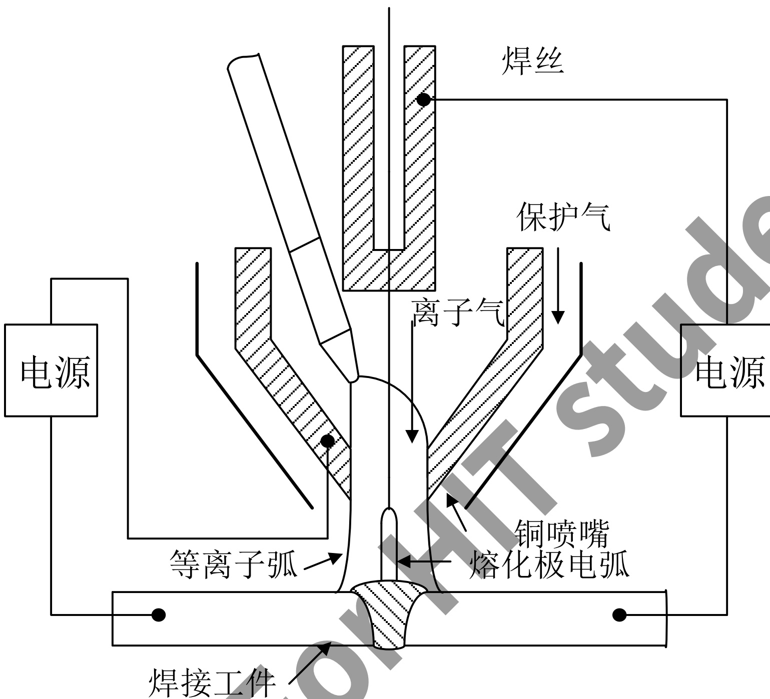
Plasma-MIG

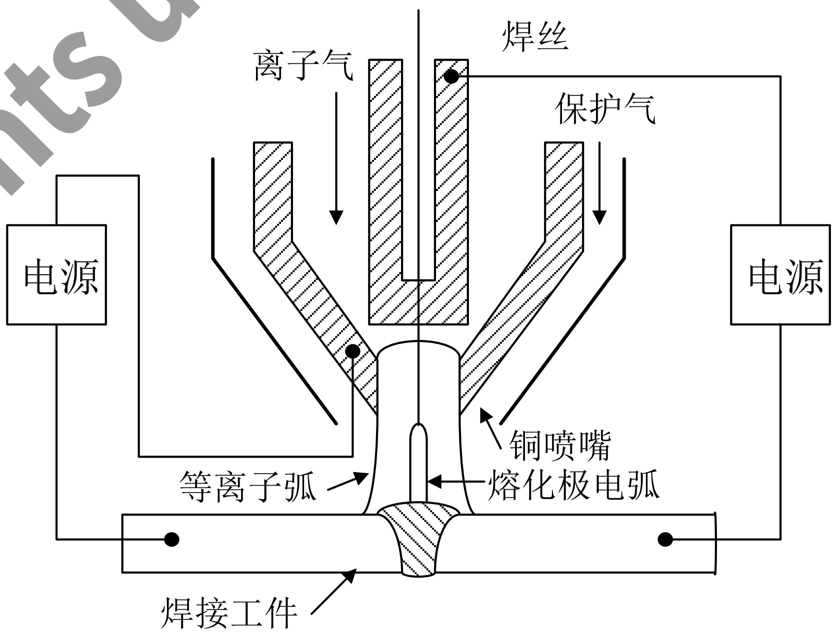
不足

- 焊接过程中等离子弧与MIG电弧同时在焊枪内燃烧，高温等离子体对焊枪设计要求较高，而且相对于常规MIG焊，焊枪体积偏大；
- 焊接参数较多，Plasma-MIG焊包含了等离子弧与常规MIG焊接参数，虽然有两个电源分别供电，但是由于两个电弧间的相互作用，使得其中一些焊接参数发生耦合，参数匹配及其优化比较复杂。
- 只能自动焊

PAW-MIG的焊枪

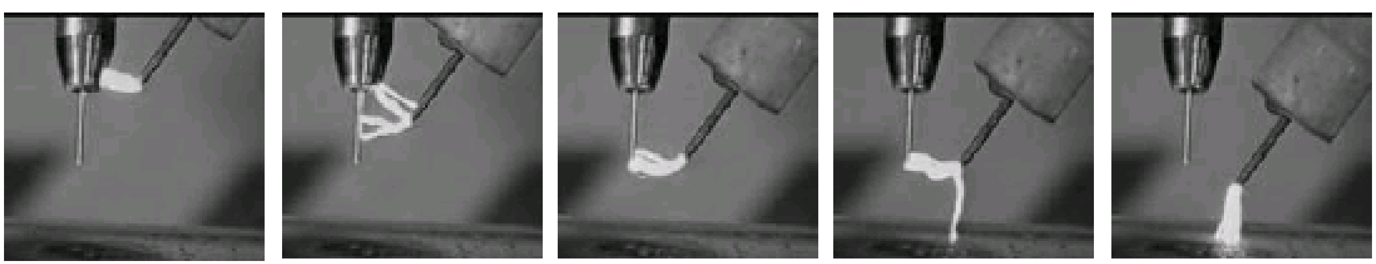
- 按照产生等离子弧电极的形式，焊枪分为偏置钨极式和喷嘴式两种





置极式Plasma-MIG焊枪

- **1972**年荷兰飞利浦公司的**W. G.Essers**和**A. C. Liefkens**首先设计。
- 偏置钨极与中心轴的角度以及钨极尖端与熔化极喷嘴的间距都会影响到焊接过程稳定性，如果设计不当会导致焊枪不能起弧，甚至造成串弧现象发生而使焊枪损坏。
- 由于**Plasma-MIG**焊多采用直流反接的形式，当等离子电源电流较大时，钨极烧损比较严重。
- 由于等离子弧与**MIG**弧在同一把焊枪内燃烧，等离子弧温度高达**13000K**，高温对焊枪内部的零件设计要求很高，尤其是焊接低碳钢或不锈钢时采用非惰性气体时，如果焊枪的水冷系统设计不完善，容易烧损焊枪。

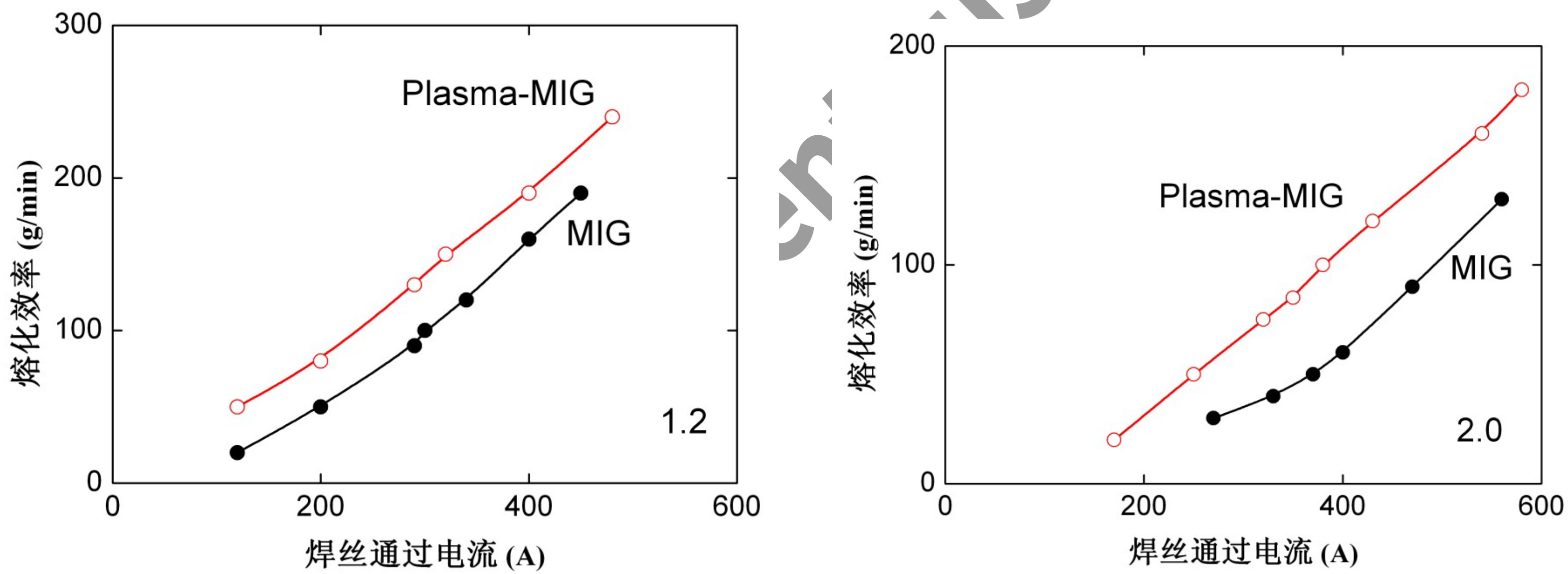


喷嘴式Plasma-MIG焊枪

- **W. G. Essers等设计**
- 相对于偏置钨极式焊枪，它具有使用寿命长、等离子电弧稳定等优点

熔敷效率

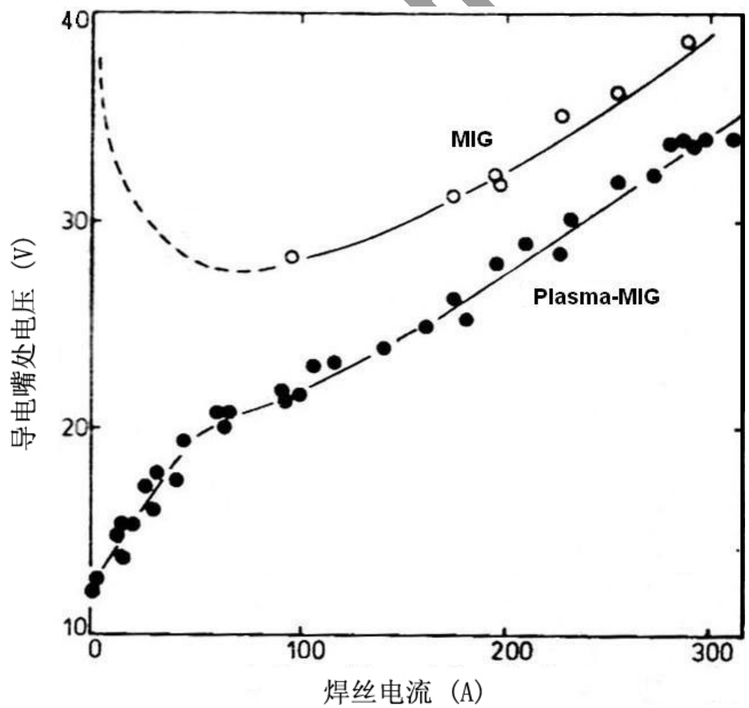
- 焊丝不仅被通过焊丝的电流和熔化极电弧加热，而且还被周围的等离子弧加热，焊丝的温度升高使得焊丝的电阻率随之变大，从而进一步加大了焊丝电流所引起的电阻热与焊丝温度，起到了预热焊丝的效果，明显地提高了焊丝熔化速率。



a) 1.2mm 低碳钢焊丝　　　　b) 2.0mm 低碳钢焊丝
熔化率与焊丝电流关系曲线 (等离子电流90A，干伸长28mm)

静特性

- 在流过焊丝电流相同的条件下，**Plasma-MIG**焊熔化极电压要低于**MIG**焊电压，当熔化极电流为零时，熔化极电压并不为零，这也间接证明**Plasma-MIG**焊的焊丝电流并不是由熔化极与工件间电压决定的。由于等离子弧的存在，焊丝电流的调节范围很宽，可以从零到几百安培，在整个过程中，电弧平稳无飞溅。



应用

- **Plasma-MIG**用于焊接汽车轮毂。大多数汽车轮毂都是由轮圈和轮辐组成，然后用一道环焊缝焊起来，通常采用CO_2自动焊完成，焊接过程中有飞溅。**Plasma-MIG**焊是无飞溅的，因此可省去清理飞溅工序，用**1.2mm**的焊丝对**2.5mm**厚轮圈和**4.5mm**厚轮辐进行焊接，焊接速度可以达到**1.45m/min**，等离子电流**80A**，熔化极焊接电流**300A**，送丝速度为**7.2m/min**。
- **Plasma-MIG**用于铝法兰与管道的焊接。管道长**1.5m**，外径为**210mm**。如采用**MIG**方法焊接，焊接坡口需要三道填充，两个工人要花费一天才能完成**12**个铝管与法兰的焊接。而采用**Plasma-MIG**方法焊接时，接头采用单道焊，完成相同的焊接工作量仅需要**1**小时，效率显著提高。
- 瑞典的**Specialtill verkningar**钢铁生产厂用**Plasma-MIG**焊代替埋弧焊来修理连铸生产在线的滚轮，不仅节省了耗费，堆焊表面需要的机械加工量更小，而且延长了其使用寿命，熔敷速度达**9-10Kg/h**。美国犹他州**Valtek**公司使用**Plasma-MIG**焊接方法替代**TIG**后，阀的耐磨寿命提高了**4**倍。

Super-MIG, by PLT

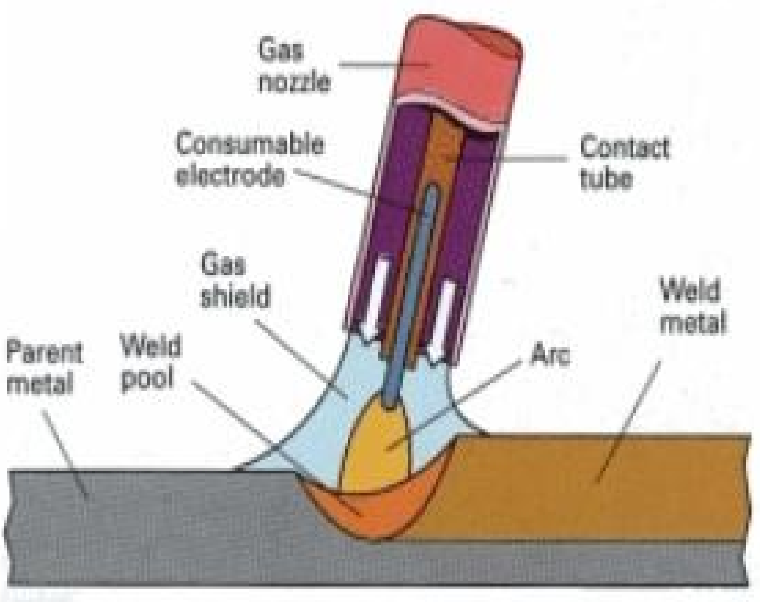
- Super-MIG® is a patented hybrid process, combining plasma and MIG/MAG into a single welding torch. The plasma operates in the “keyhole” welding mode for deep penetration and the MIG operates in a “conduction” mode to fill the void created by the plasma, thus stabilizing the plasma keyhole.

http://www.plasma-laser.com

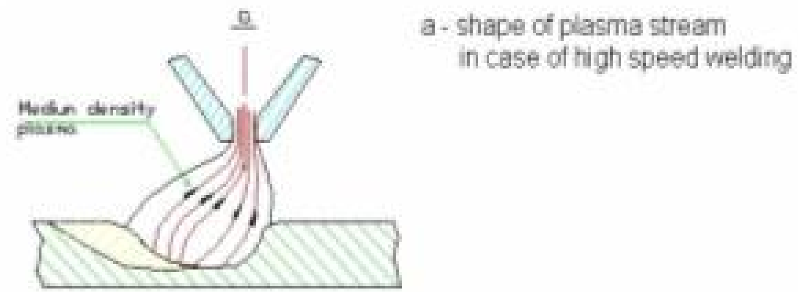
Super-MIG, by PLT

Welding Method

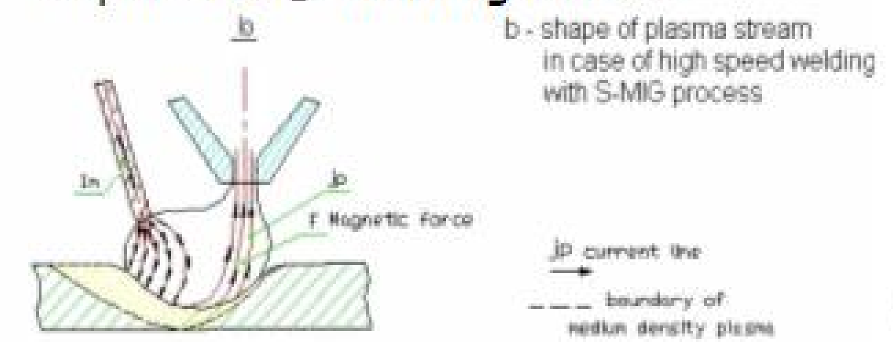
Conventional MIG/GMAW Welding Method



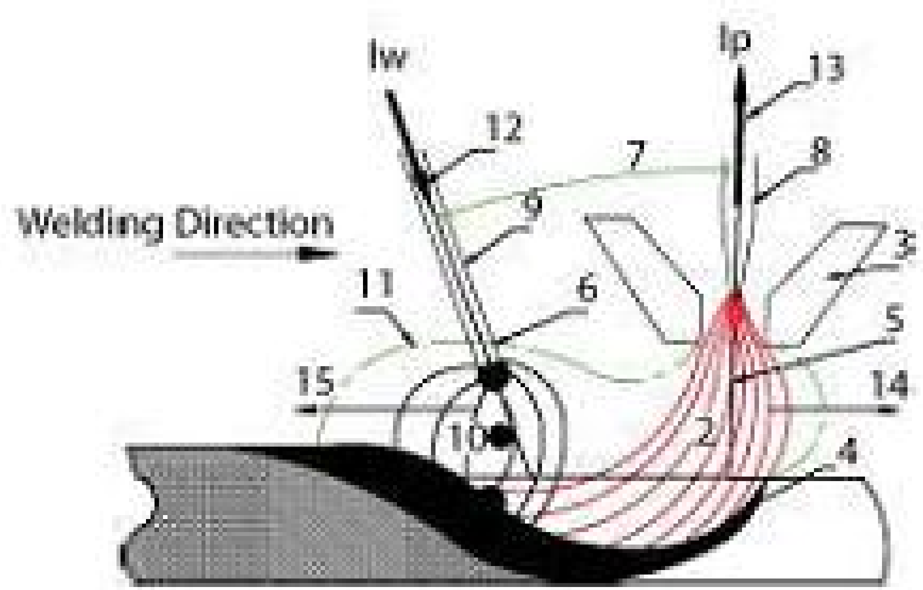
Plasma Welding Method



Super-MIG® Welding Method



- The welding approach combines a plasma arc and a GMAW arc into one process. These elements detail the process:
    - (1) workpiece;
    - 2) plasma jet;
    - (3) plasma nozzle;
    - (4) melting metal;
    - (5) plasma arc electrode axis;
    - (6) wire axis;
    - (7) angle between electrode's axes;
    - (8) tungsten electrode;
    - (9) consumable electrode (wire);
    - (10) GMAW arc;
    - (11) plasma;
    - (12) wire current (Iw) direction;
    - (13) plasma current (Ip) direction;
    - (14) magnetic forces (F) applied to plasma arc;
    - (15) magnetic forces (F) applied to GMAW arc.



Super-MIG® Benefits compared to conventional MIG / MAG / SAW

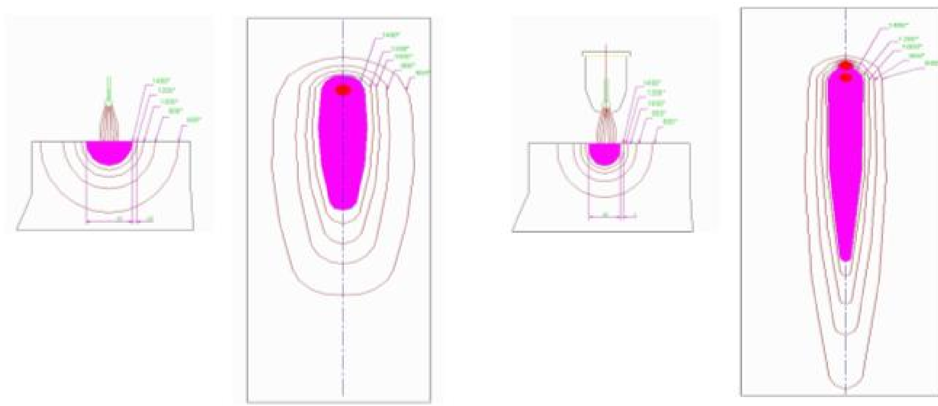
- Higher welding speeds (2-3 times faster than MIG / MAG / SAW).
- Produces true lap welds.
- In many cases can substitute Laser installations.
- Improved part quality - significant reduction in residual deformation - due to reduction of welding heat input (narrow Heat Affected Zone - "HAZ").
- Reduced wire consumption - less edge preparation requirements.
- Easily integrated into traditional MIG / MAG applications.
- Higher quality welds for same range of weldable materials (MIG/TIG/Plasma).
- Significant reduction in weld spatter.
- Adaptable to popular MIG / MAG welders, such as Lincoln, Miller, Cloos, Panasonic, OTC, ESAB, etc.
- Compatible with analog MIG welder controls.

Super-MIG® Benefits compared to conventional MIG / MAG / SAW

Super-MIG® Heat Distribution

Reduced part distortion due to a narrower Heat Affected Zone ("HAZ")

Conventional MIG/GMAW   Super-MIG®



Thickness, mm	GMAW					Plasma / GMAW				
	Speed		Power	Heat		Speed		Power	Heat	
	IPM	cm/min	kW	joules per		IPM	cm/min	kW	joules per	
				inch	cm				inch	cm
1.6	60	23.62	7.92	7.920	3.118	160	62.99	8.96	3.360	1.323
2	60	23.62	8.50	8.500	3.346	120	47.24	10.60	5.300	2.087
3	50	19.69	9.29	11.150	4.390	90	35.43	12.75	8.500	3.346

- The process includes a plasma electrode within the hybrid GMAW torch. This electrode establishes an arc at the leading position of the welding process, and a “keyhole” is created within the base material by the plasma arc. GMAW follows and operates typically in the conduction welding mode to fill the void created by the plasma arc.
- The process uses a negative plasma arc electrode and a positive GMAW electrode to achieve maximum processing speed and to operate in the spray transfer mode.
- The magnetic force F causes deflection of the plasma arc toward the front of the weld pool, thus compensating for the plasma arc’s natural tendency to trail behind the torch axis during high-speed welding.
- The resultant effect is a substantial increase in the plasma arc rigidity and stability leading to a substantial increase of penetration depth and welding speed.

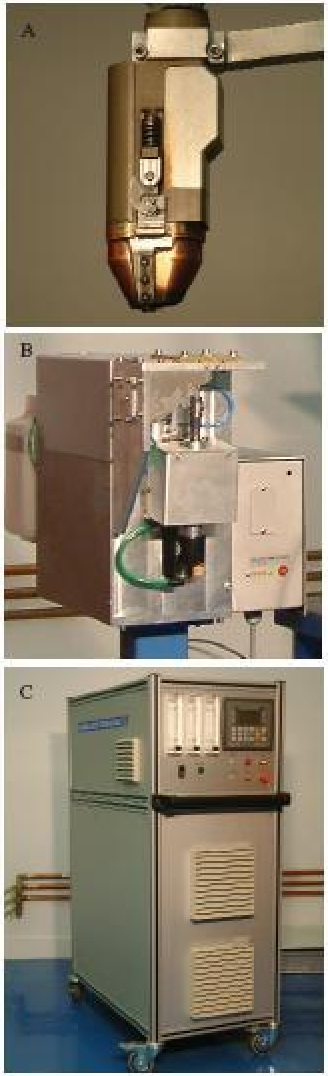


Fig. 2 — System components. A — Torch; B — cleaning station; C — interface.

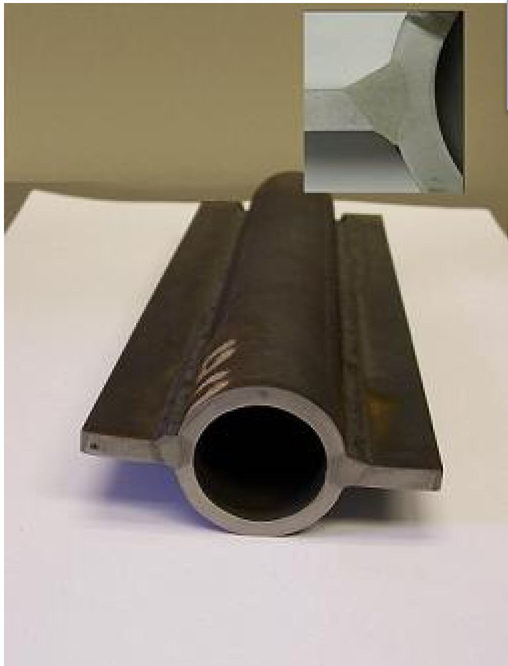
- The interaction between the plasma arc flow and the GMAW arc promotes wire heating and current transfer at the anode spot (at the end of the GMAW welding wire) where the molten weld metal droplets form and subsequently detach. The resultant magnetic force F, shown in Fig. 3, occurs as a result of the interaction of the electric currents passing through the two electrodes.
- Integral to the technology is a patented SoftStart™ arc ignition technology to eliminate the effect of electromagnetic interference during the establishment of the pilot arc, which also substantially increases the nonconsumable plasma electrode's lifetime.
- The plasma gas is typically argon whereas, depending on the materials to be welded, the GMAW shielding gas is an argon mix.
- The interface controls the hybrid weld process, stores multiple welding programs, monitors the welding gas flow, and allows for the adjustment of the welding gas mixture. The interface contains the plasma arc power source, pump, and reservoir for a recirculatory cooling system. Included also is the arc ignition device.

Applications

Joint type:	T-joint
Material Spec.:	Low Carbon Steel
Position:	Flat
Material Thickness:	Tu[illegible]
Filler Wire:	ER[illegible]
Welding Speed:	0.97m/min (38ipm)
Wire Feed Speed:	16m/min (630ipm)
Plasma Arc:	200A
Plasma Gas:	Argon
MIG Voltage:	31V
Shielding Gas:	75%Argon + 25%CO_2

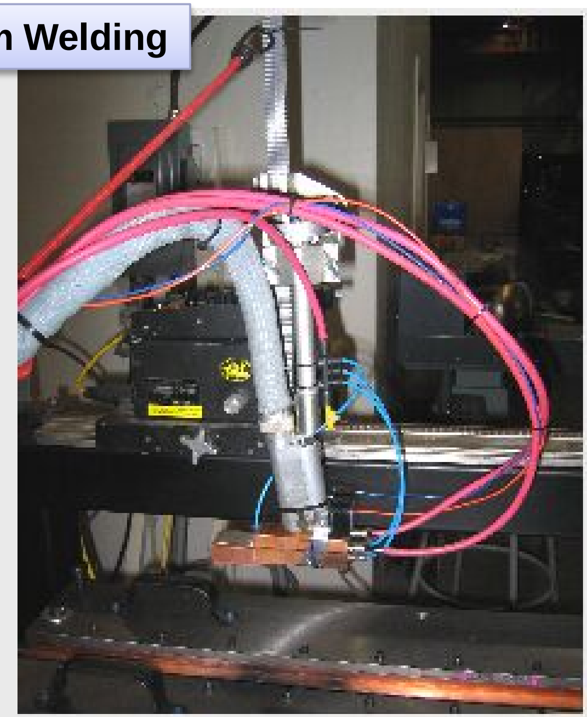
电流30A电弧压力分布对比

Applications



Tube-to-Fin Welding Mild Steel tube dia.: 1/4"
Welding speed: 35 in/min

Titanium Welding

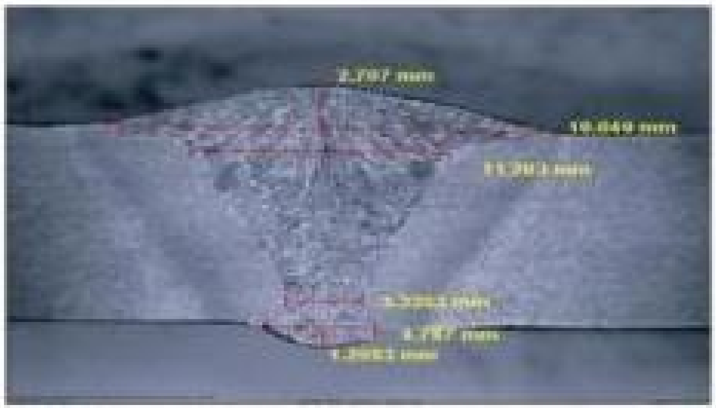


Applications

MIG/MAG P.S.: FRONIUS TRANS-PULSE SYNERGIC 5000

WELD TYPE: BUTT12mm+12mm LCS

GAS MIXTURE: AR=80%/CO2=20%



Picture 1

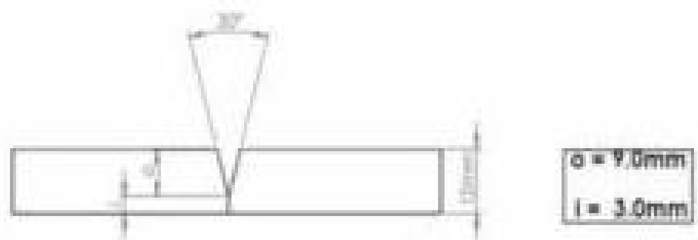
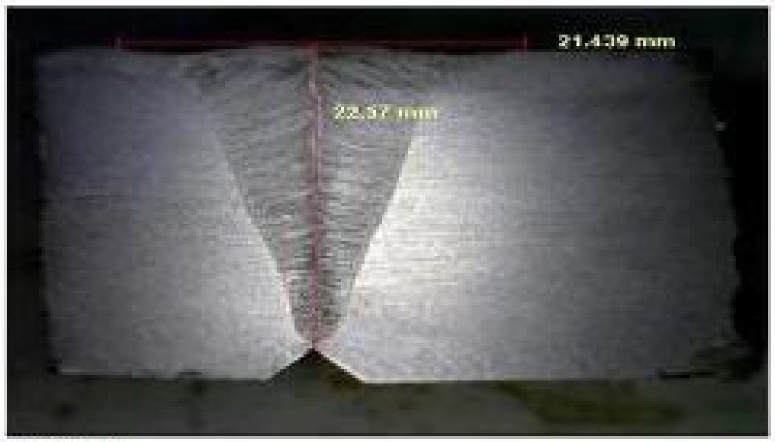


Figure 1

WELD #	PL. CUR. [A]	SPEED m/min	WIRE SPEED m/min	WIRE TYPE & DIA	MIG VOLT. [V]	MIG CUR. [A]	PHOTO	EDGE PREPARATION
Pic. 1 - 1	190	0.4	22	ER70S-6 ø1.2mm	35.5	520	Picture 1	Figure 1

MIG/MAG P.S.: MILLER AUTO AXCESS 675
WELD TYPE: STAINLESS STEEL BUTT 25mm +25mm SAE 321
GAS MIXTURE: AR=98%/CO2=2%



Picture 4

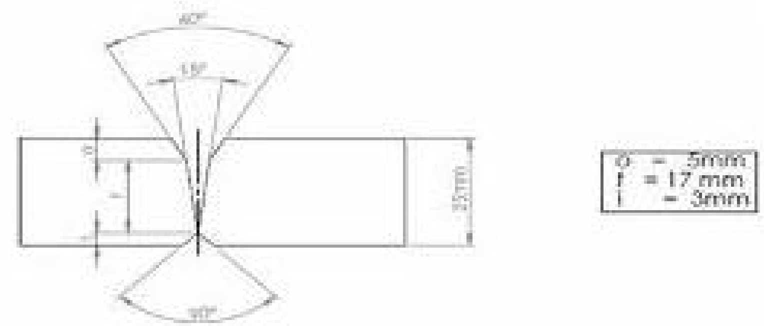


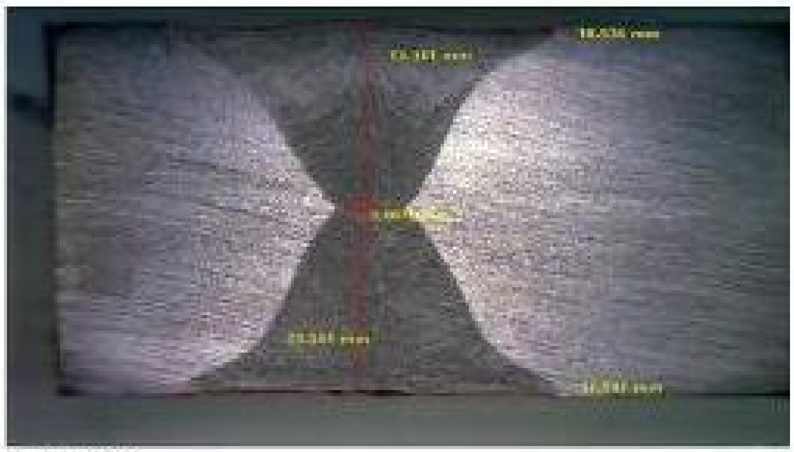
Figure 4

WELD #	PL. CUR. [A]	SPEED m/min	WIRE SPEED m/min	WIRE TYPE & DIA.	MIG VOLT. [V]	MIG CUR. [A]	PHOTO	EDGE PREPARATION
Pic. 4 - 1	340	0.4	15.5	ER347Lø1.6mm	33	596	Picture 4	Figure 4

MIG/MAG P.S.: FRONIUS TRANS-PULSE SYNERGIC 5000

WELD TYPE: STAINLESS STEEL BUTT 25mm +25mm SAE 321

GAS MIXTURE: AR=90% CO_2=5% O_2=5%



Picture 6

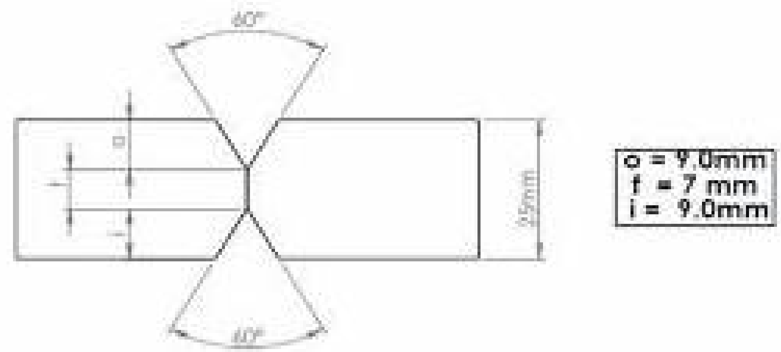
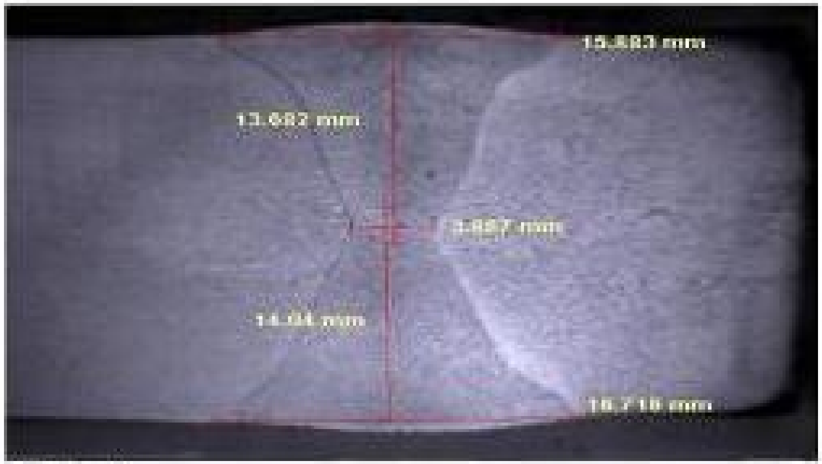


Figure 6

WELD #	PL. CUR. [A]	SPEED m/min	WIRE SPEED m/min	WIRE TYPE & DIA.	MIG VOLT. [V]	MIG CUR. [A]	PHOTO	EDGE PREPARATION
Pic. 6 - 1	340	0.6	12	ER347Lø1.6mm	31	467	Picture 6	Figure 6
Pic. 6 - 2	340	0.55	11	ER347Lø1.6mm	30	445		

MIG/MAG P.S.: FRONIUS TRANS-PULSE SYNERGIC 5000
WELD TYPE: STAINLESS STEEL BUTT 25mm +25mm SAE 321
GAS MIXTURE: AR=90% CO2=5% O2=5% (continued)



Picture 7

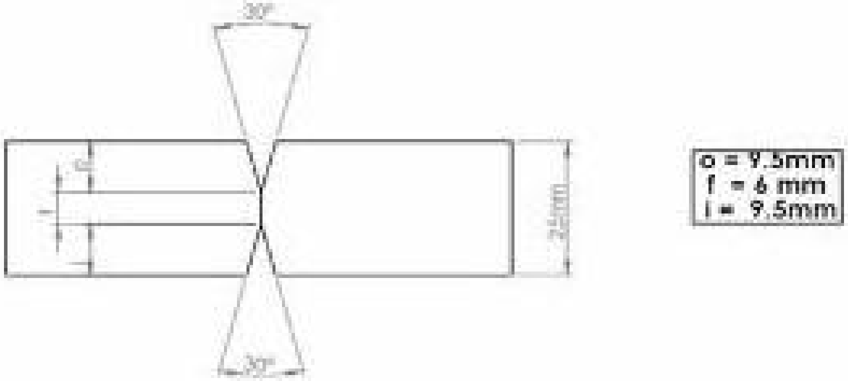


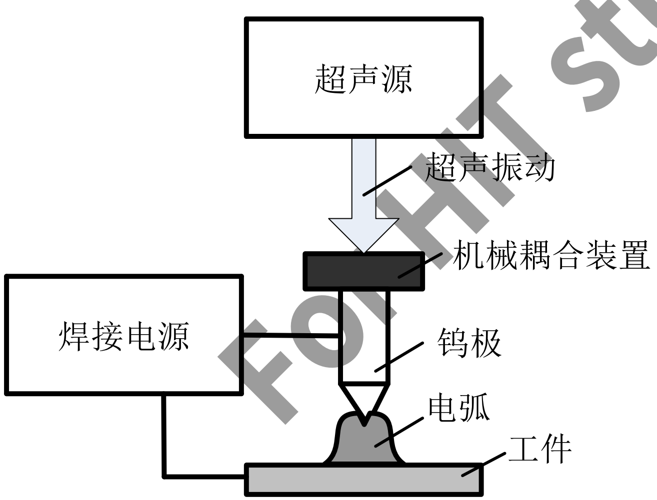
Figure 7

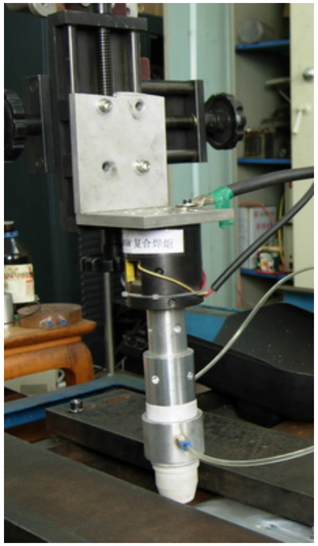
WELD #	PL. CUR. [A]	SPEED m/min	WIRE SPEED m/min	WIRE TYPE & DIA.	MIG VOLT. [V]	MIG CUR. [A]	PHOTO	EDGE PREPARATION
Pic. 7 - 1	340	0.55	14	ER347Lø1.6mm	27	480	Picture 7	Figure 7
Pic. 7 - 2	340	0.55	14	ER347Lø1.6mm	27	486		

超声-TIG复合焊接

Ultrasonic assisted TIG welding

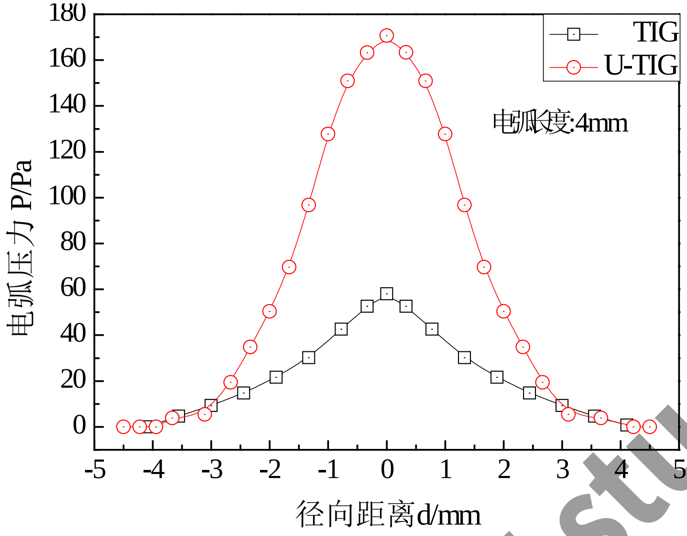
- **2007**年由哈工大焊接国家重点实验室提出，已获发明专利。
- 超声的产生是通过超声换能器将超声电源输出的电信号转换成机械振动，最后传递给焊接电弧以实现超声对焊接过程的影响。
- 主要由超声电源、机械振动系统、超声耦合部分及焊接电源组成。工作原理为：**50 Hz**交流电经过超声电源转化为**20 kHz**的脉冲电信号，施加在超声振动系统上，由换能器转化为机械振动，最终通过复合焊炬传递给焊接电弧，以期影响焊接熔池，改善焊接质量，提高焊接效率。

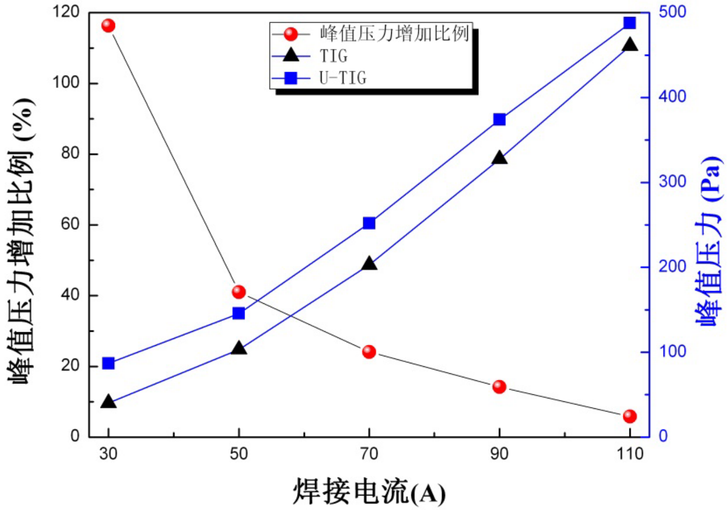




电弧特性

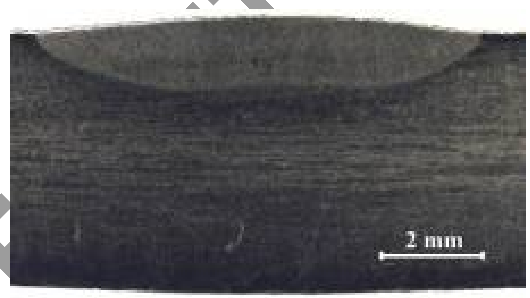
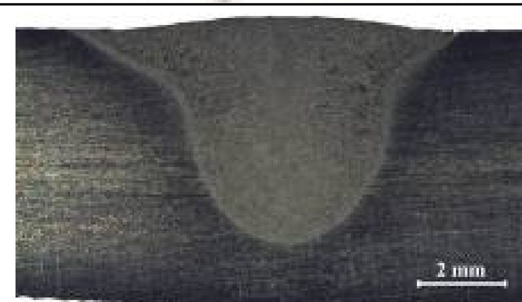
- 复合电弧的压力峰值高于常规电弧，压力整体水平复合电弧明显高于常规TIG焊，并且电弧的挺直性也将明显得到提高。





电流30A电弧压力分布对比

焊缝熔深的对比

焊接电流	常规 TIG	U-TIG
50A		
100A		
150A		

微观组织的对比

a) TIG

b) U-TIG

Sus304 stainless steel

End of chapter 5

Q&A?