Laser Hybrid, RAPID ARC and Tandem MAG Welding, a Comparative Study

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Welding Methods Compared

- Laser MAG
- Tandem MAG
- RAPID ARC
- MAG (reference)

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Material tested

6 mm steel plate

Steel	C	Si	Mn	P	S	N	Cr	Ni	Cu	Al	Nb	Mo	V
Domex420MC	0.067	0.03	1.11	0.006	0.002	0.006	0.03	0.06	0.02	0.04	0.03	-	-
WELDOX900	.173	.220	1.38	.009	.003	.0053	.247	.048	.021	.065	.015	.493	.02

Filler wire

Filler wire	$Rp_{0,2}$ (MPa)	R_m (MPa)	A_5 (%)	Chemical composition (weight %)					
				C	Si	Mn	Cr	Ni	Mo
OK Autrod 12.51	470	560	26	0,1	0,9	1,5	-	-	-
OK Autrod 13.13	690	770	20	0,1	0,5	1,1	0,5	0,5	0,2
OK Autrod 13.31	850	890	17	0,1	0,7	1,7	0,3	1,9	0,5

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Experimental Matrix

Joint type	Material/Surface cond.	Filler wire	Joint preparation
Butt joint	Domex 420 MC/ Pickled	OK Autrod 12.51	Laser MAG: V-joint 7º Tandem MAG: V-joint 60º RAPID ARC: V-joint 7º MAG: Milled I-joint
	WELDOX 900/ Sand blasted	OK Autrod 13.31	
Fillet joint	Domex 420 MC/ Pickled	OK Autrod 12.51	Milled square butt
	WELDOX 900/ Sand blasted	OK Autrod 13.13	

Plate thickness = 6 mm

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Evaluation of Welded Joints

Quality determination:

- Quality level B
- Deformation measuring
- Optical microscope

Non-destructive testing:

- X-ray
- Penetrant test

Destructive testing:

- Tensile test
- Impact test (Charpy V)
- Hardness test (HV5)
- Bend test
- Fatigue test

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Experimental Setup for Laser MAG Welding

Equipment used

Laser: Rofin Sinar RS6000 CO_2-laser
MAG: ESAB Aristo 450W

Welding parameters

Laser power at workpiece: 5 kW
MAG pulsing time: 2 ms
MAG pulsing frequency, f = 120 -148 Hz
Shielding gas: 65%He 30%Ar 5%CO_2
Shielding gas flow: 24 l/min
Filler wire: ϕ = 1.0 mm

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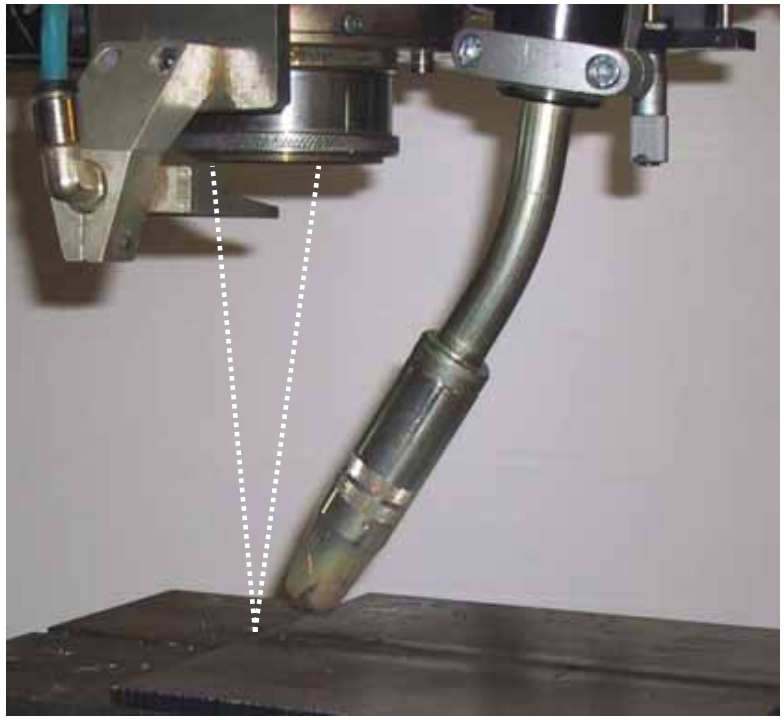
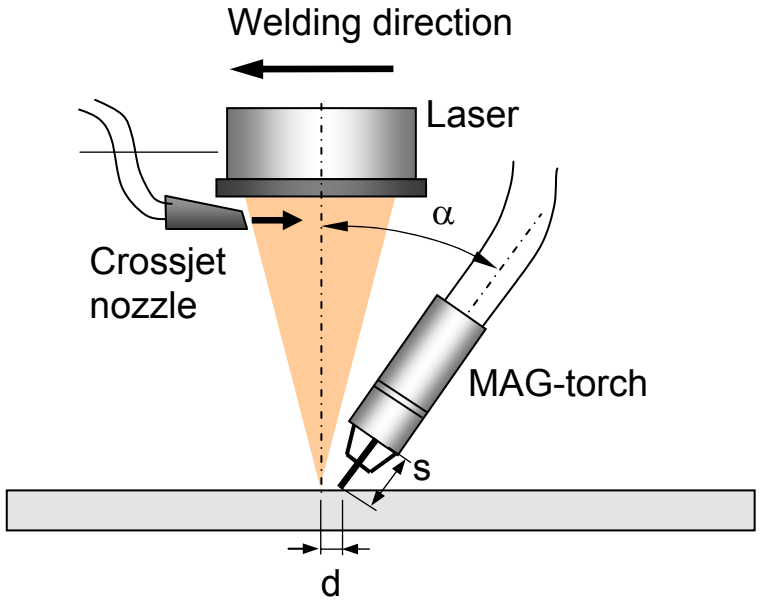
Experimental Setup for Laser MAG Welding

Butt joint





Stickout (s): 18-21 mm
Angle of MAG incidence (α): 35°
Distance wire-focal point (d): 2 mm

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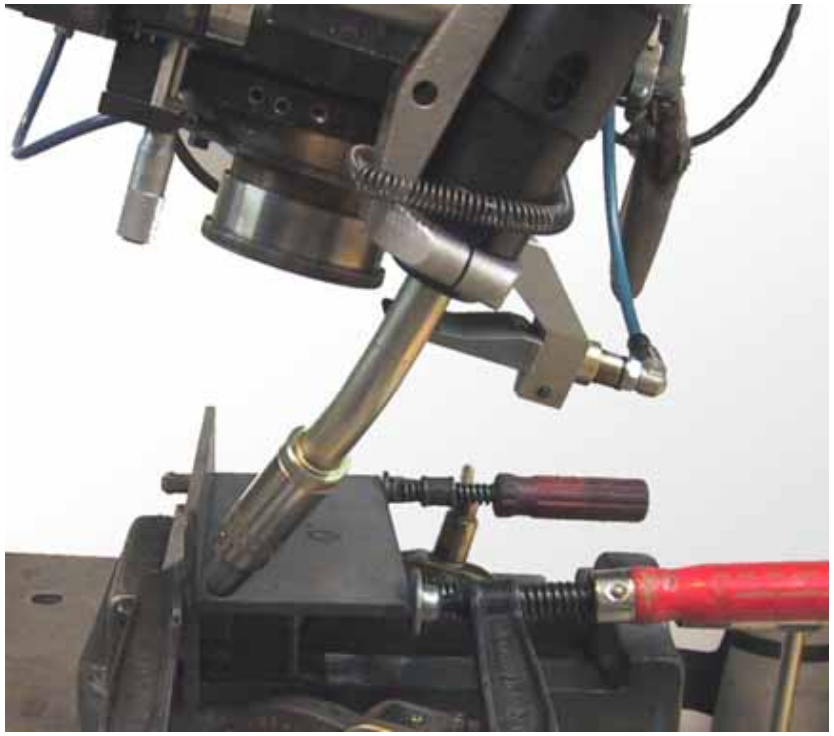
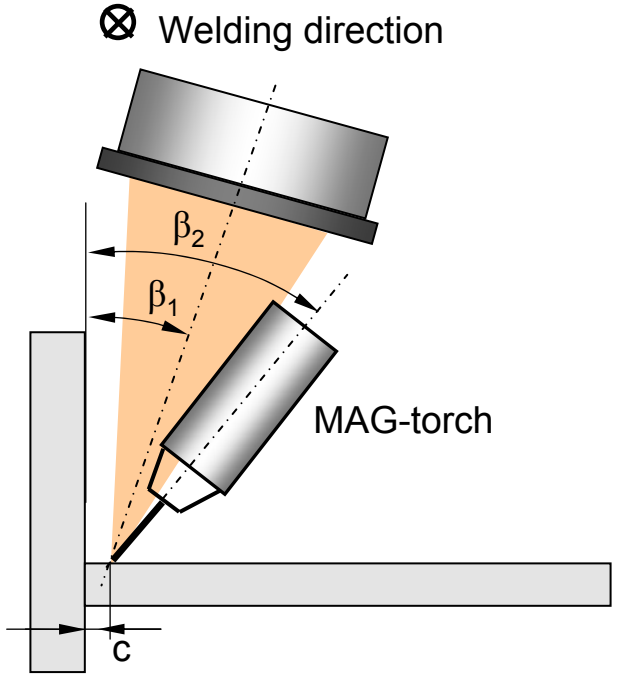
Experimental Setup for Laser MAG Welding

Fillet joint





Angle of laser incidence (β_1): 10°

Angle of MAG incidence (β_2): 20°

Distance joint edge to focal point position (c): 0-2 mm

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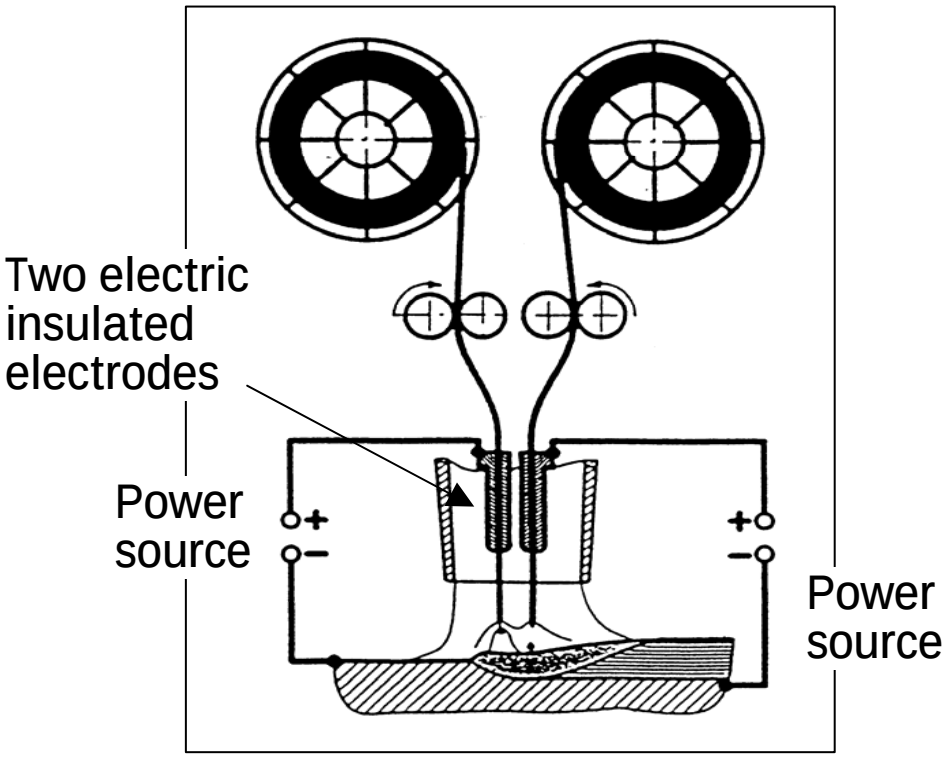
Experimental Setup for Tandem MAG Welding



- Freedom in choice and positioning of electrodes
- Positioning of the elektrodes important
- Front electrode often with higher data
- Long melt pool gives better fusion

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Experimental Setup for Tandem MAG Welding

ESAB Aristo 2000, 2 x 500 A

Welding parameters:

Arc type: Spray + spray
Short + spray

Electrode inter distance: 20 mm

Shielding gas: 92%Ar8%CO_2

Shielding gas flow: 35 - 40 l/min

Filler wire: ϕ = 1.2 mm

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Experimental Setup for RAPID ARC Welding

- Standard MIG/MAG welding equipment can be used
- High wire feed
- Argon rich shielding gas
- Long electrode stickout
- Low arc voltage
- Regulated inductance advantageous
- Deep and wide welds
- Heat input is lower than standard MIG/MAG

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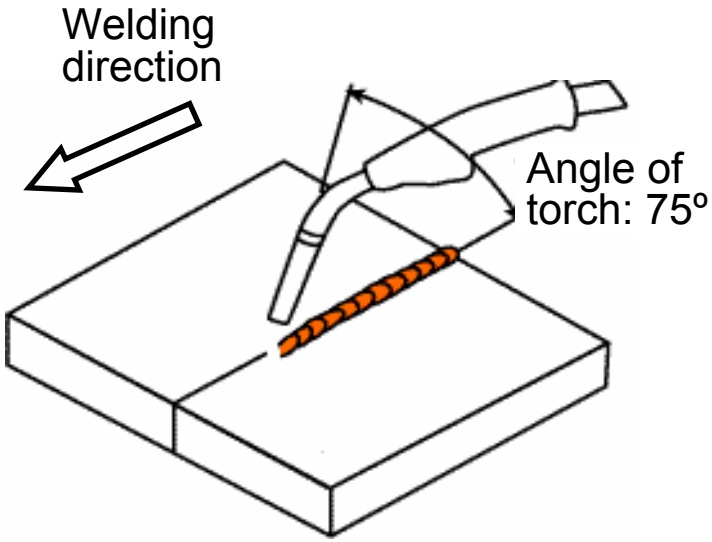
Experimental Setup for MAG Welding



Welding parameters

Shielding gas composition	**77% Ar 23%CO_2,**
Shielding gas flow	**15 l/min**
Inner diameter of the nozzle	**16 mm**
Backing type	**Ceramic (Butt weld)**
No of weld passes / welded joint	**1**
Diameter of electrode	**1,2 mm**
Current	**304A (DC+)**
Voltage	**29 V**

Welding data gives a cooling time $t_{8/5}$= 5 - 20 s
Priority to high welding speed

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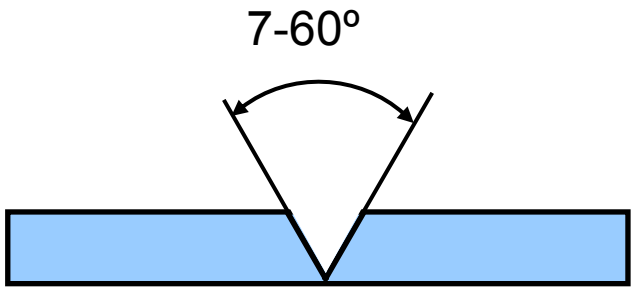
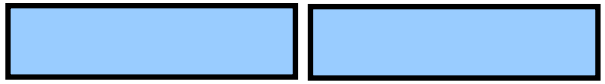
Joint configuration

Butt Joints





Laser MAG: 7º
Tandem MAG: 60º
RAPID ARC: 7º + 1 mm root gap

MAG: Gap = 1 mm

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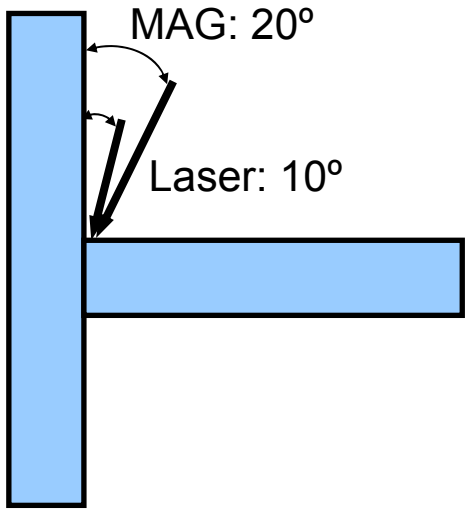
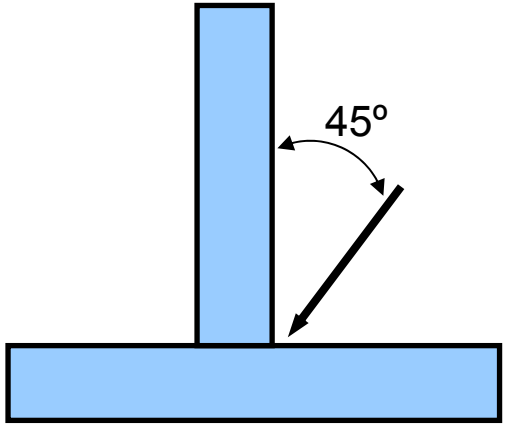
Joint configuration

Fillet Joints



Laser MAG



Tandem MAG
RAPID ARC
MAG

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Results

Cross Sections of Welded Butt Joints

Laser MAG

v = 2.0 m/min
Wire: Φ =1.0 mm
v_{WIRE} = 8 m/min
Heat: 0.24 kJ/mm

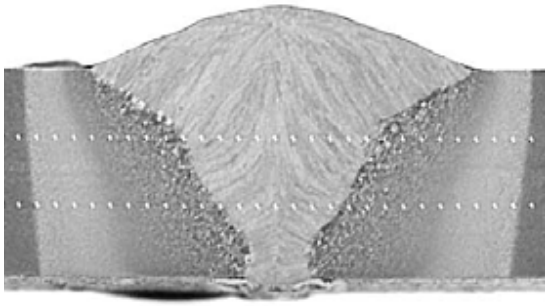
Tandem MAG

v = 1.5 m/min
Wire: Φ =1.2 + 1.2 mm
v_{WIRE} = 15 + 11 m/min
Heat: 0.71 kJ/mm

RAPID ARC

v = 1.0 m/min
Wire: Φ =1.0 mm
v_{WIRE} = 17 m/min
Heat: 0.45 kJ/mm

MAG



v = 0.53 m/min
Wire: Φ =1.2 mm
v_{WIRE}: N/A
Heat: 0.80 kJ/mm

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Results

Cross Sections of Welded Fillet Joints

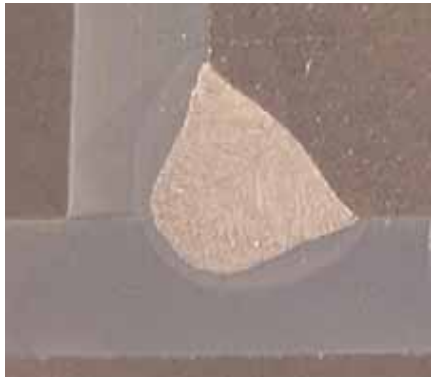
Laser MAG

v = 1.0 m/min
Wire: Φ =1.0 mm
v_{WIRE} = 8 m/min
Heat: 0.43 kJ/mm

Tandem MAG

v = 1.5 m/min
Wire: Φ =1.2 + 1.2 mm
v_{WIRE} = 21 + 15 m/min
Heat: 1.1 kJ/mm

RAPID ARC



v = 1.1 m/min
Wire: Φ =1.2 mm
v_{WIRE} = 25 m/min
Heat: 0.88 kJ/mm

MAG

v = 0.45 m/min
Wire: Φ =1.2 mm
v_{WIRE}: N/A
Heat: 0.96 kJ/mm

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Results

Welding Speed and Heat Input

Process	Butt weld		Fillet weld	
	Welding speed (m/min)	Input energy (kJ/mm)	Welding speed (m/min)	Input energy (kJ/mm)
Laser MAG	2.0	0.24	1.0	0.43
Tandem MAG	1.5	0.71	2.0	1.11
RAPID ARC	1.0	0.45	1.1	0,88
MAG (Ref)	0.53	0.96	0.45	0,80

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Results

Tensile Strength of the Butt Welds

Process	$R_{p0,2}$ (N/mm^2)		Rm (N/mm^2)		A_5(%)		Position	
	DX420	WX900	DX420	WX900	DX420	WX900	DX420	WX900
Laser MAG	448	995	534	1035	23	15	BM	HAZ
Tandem MAG	444	1007	534	1051	24	17	BM	HAZ
RAPID ARC	445	999	531	1048	21	15	BM	BM
MAG	-	950	-	1021	-	10		HAZ

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Impact Strength of the Butt Welds

Process	Position	DX420 (- 20°C, J/cm²)	WX900 (- 40°C, J/cm²)
Laser MAG	Weld metal	307	55
	Fusion line	255	38
	Fusion line + 1 mm	227	37
Tandem MAG	Weld metal	190	40
	Fusion line	250	44
	Fusion line + 1 mm	263	34
RAPID ARC	Weld metal	230	38
	Fusion line	250	43
	Fusion line + 1 mm	268	63
MAG	Weld metal	-	98
	Fusion line	-	55
	Fusion line + 1 mm	-	35

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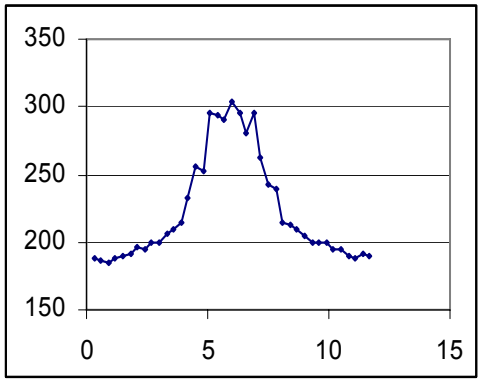
Results Hardness Test

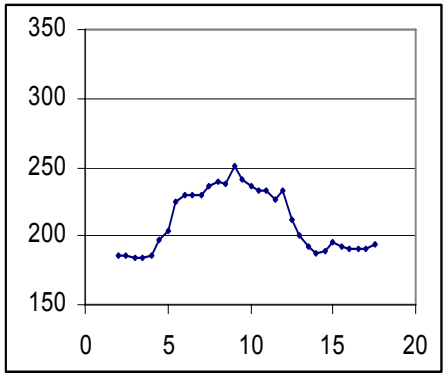
(Butt weld, HV5, 2 mm below surface)

Domex 420

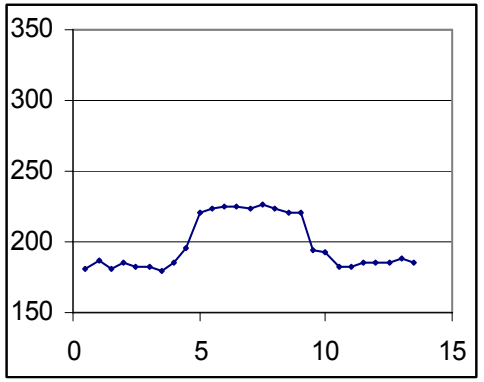
Laser MAG



Tandem MAG



RAPID ARC



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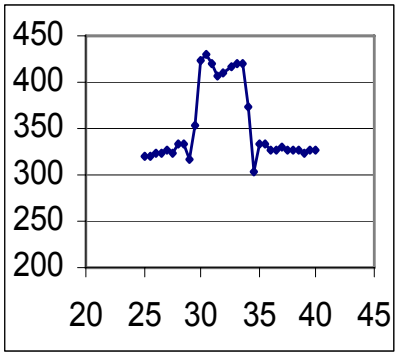
Results Hardness Test

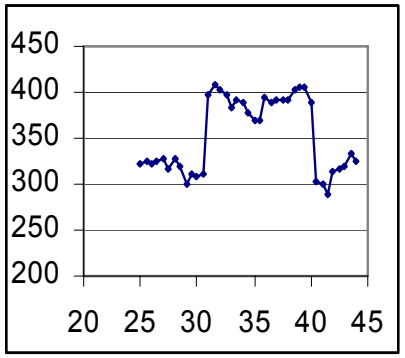
(Butt weld, HV5, 2 mm below surface)

WELDOX 900

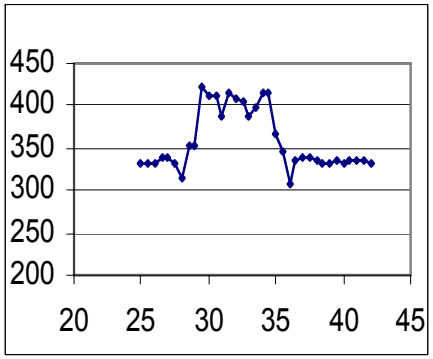
Laser MAG



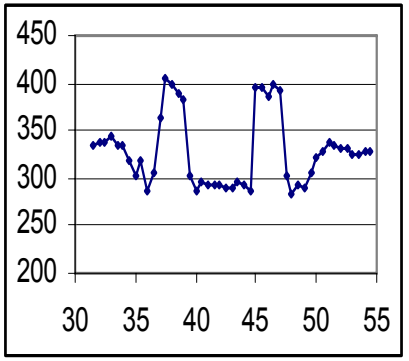
Tandem MAG



RAPID ARC



MAG



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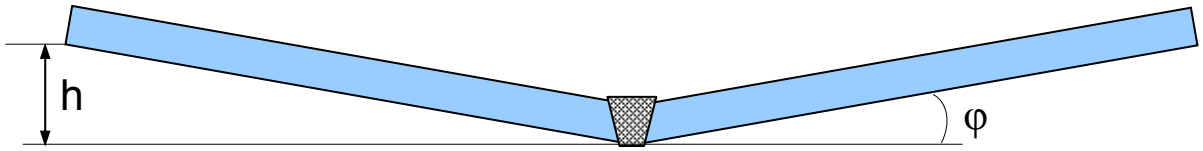
Results

Deformation Measurement



Process	h (mm)	φ (º)	Std. dev.
Laser MAG	4.9	1.4	0,3
Tandem MAG	1.8	0.5	0,1
RAPID ARC	0.8	0.2	0,2
MAG	2.5	0.7	0,8

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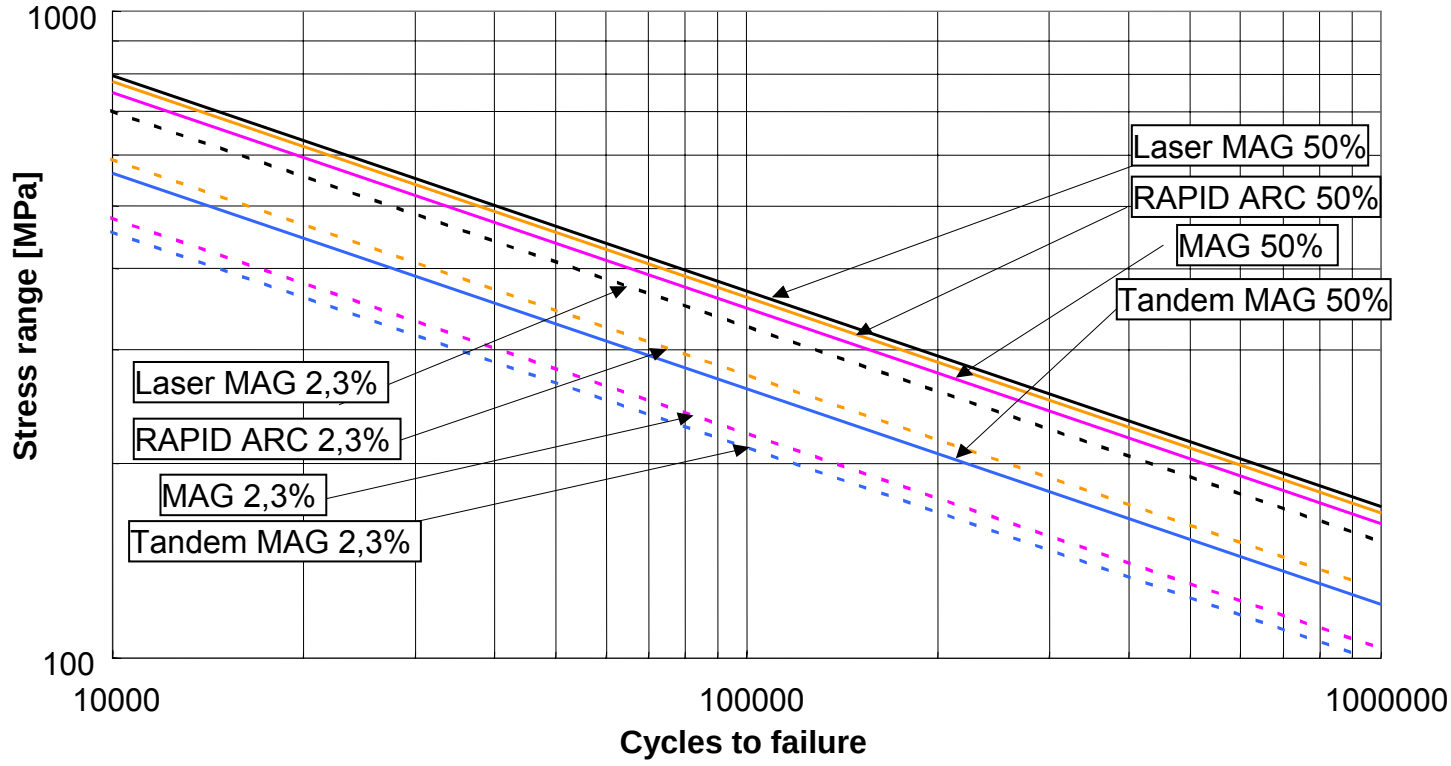
Results Fatigue Test

Stress range (constant amplitude) as a function of cycles to failure, (compensated for bending according to IIW)



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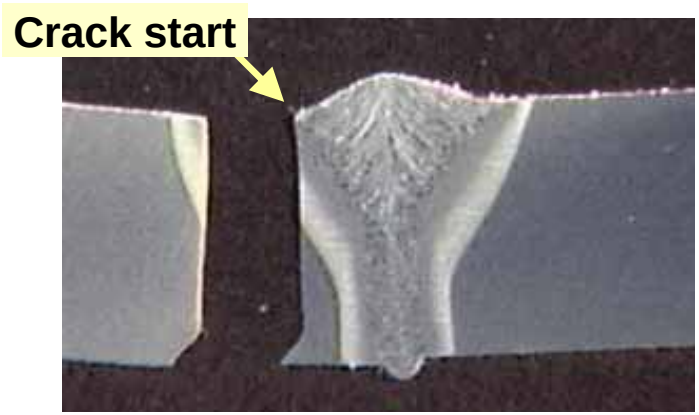
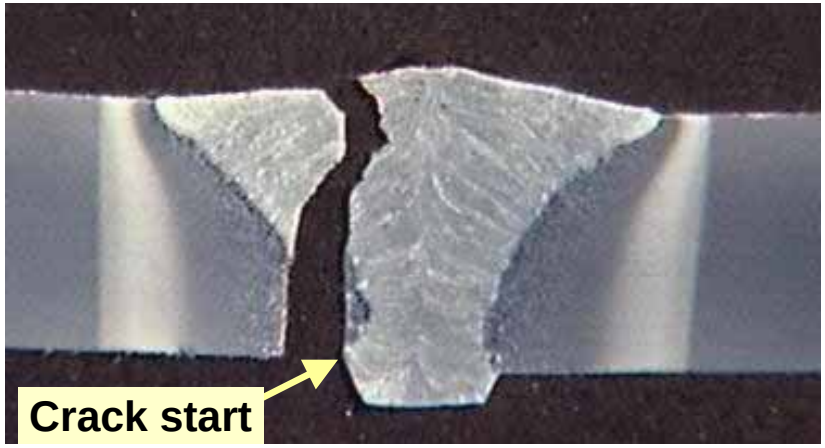
Fatigue Test Results

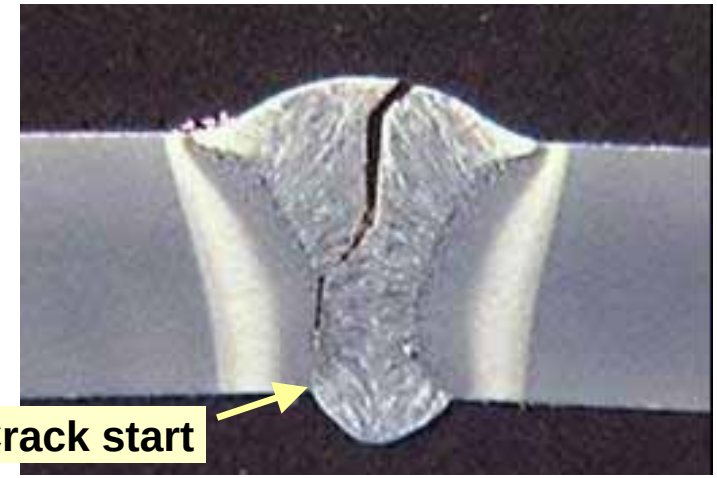
Laser MAG



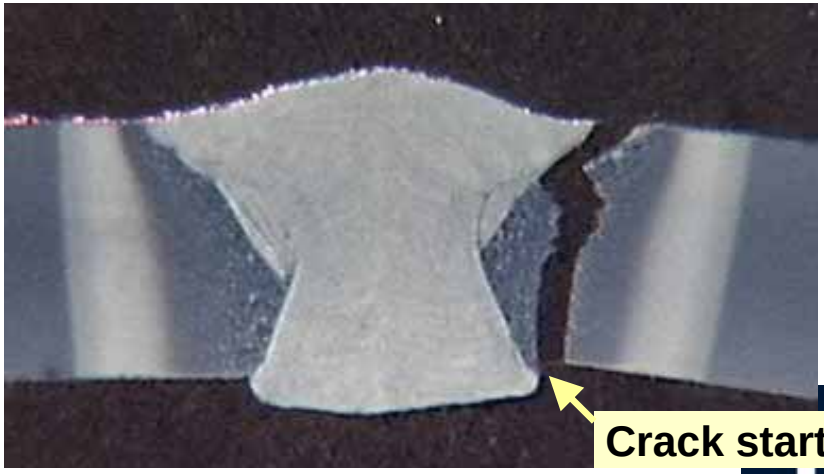
Tandem MAG



RAPID ARC



MAG



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Conclusions

- Joint design (joint angles, edges, gap etc) has a great influence to the optmum welding speed
- Weld quality level B can be achieved even at high welding speeds.
- Butt welds can be welded without root backing with Laser MAG and RAPID ARC
- Laser MAG welding of fillet welds can be fully penetrating from one side
- Fatigue tests showed that the high productive welding processes performed well compared to traditional MAG welds.

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