RESEARCH AND DEVELOPMENT

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Interreg Nord
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Contents

- CMT project and process
- Comparison: Standard MIG, pulse MIG and CMT
- Comparison of cladding processes with laser and CMT, and with Inconel 625.
- Some Examples of cladding results with 316L stainless steel, stellite 21 and Ni-WC hardfacing.

CMT project and process

Project:

- CMT - Nordic business opportunities from coating and additive manufacturing. Funded by EU program Interreg Nord 2014-2020
- Research partners: Centria University of Applied Science, Tampere University of Technology, Luleå University of Technology, Tromsø University.

Process:

- CMT: **C**old **M**etal **T**ransfer, process developed by Austrian welding power source manufacturer Fronius GmbH.
- CMT process control detects a short circuit when wire hits the melt pool, then helps to detach the droplet by retracting the wire – up to 90 times a second!
- This cyclic wire retraction helps on decreasing both spatter and heat input on process.
- Other methods/manufacturers that have similar wire-retraction feature include:
    - APW, Active Wire Process, Panasonic
    - SpeedUp, Lorch
    - PowerPulse, Dinse
    - MicroMIG, SKS
    - Controlled Short Circuit - CSC-MIG, Jetline Engineering
- All MIG/MAG welding power source manufacturers have their own methods and trade marks for digitally controlled short circuit processes, but without wire retraction feature. These include Wise from Kemppi and STT from Lincoln.

Overlay welding methods

- There are currently quite a number of different techniques for performing cladding, each with its own specific characteristics in terms of the materials employed, the quality of the clad layer and various practical issues including throughput speed, process compatibility, and cost
- Common arc welding methods include: TIG (GTAW), plasma transferred arc (PTA), MIG/MAG (GMAW), submerged arc welding (SAW)
- However, figures in the table are biased, or bit misleading in a sense that only the effecting power on a work piece is taken on comparison.

Key parameters of various cladding processes at high depositions rates [Andersson & Parker]

Cladding Process	Power (kW)	Deposition rate (kg/h)	Efficiency (kg/kW/hr)	Relative heat input/ distortion	Notes
High Power Diode Laser	7	9	1.29	1	Powder cladding rate. Expect greater efficiency & higher deposition with “dual hot wire”
Plasma Arc Welding (PTA)	7.5	5.4	0.72	3	250 A x 30 V + “hot wire” Heat input: 2 kJ/mm
Gas Tungsten Arc Welding (GTAW)	6	4.5	0.75	6	400 A x 15 V + “hot wire”
Gas Metal Arc Welding (GMAW)	12	7.6	0.63	10	400 A x 30 V, Ø2,8 mm wire Heat input: 1.5-1.7 kJ/mm
Submerged Arc Welding (SAW)	25	13.5	0.54	20	800 A x 32 V, Ø4 mm wire, DC Heat input: 2.2 kJ/mm
CMT (GMAW)*	4	5	1.25	?	175 A x 16,2 V, Ø1.2 mm wire Heat input: 0.2–0.3 kJ/mm

* Results from CMT project

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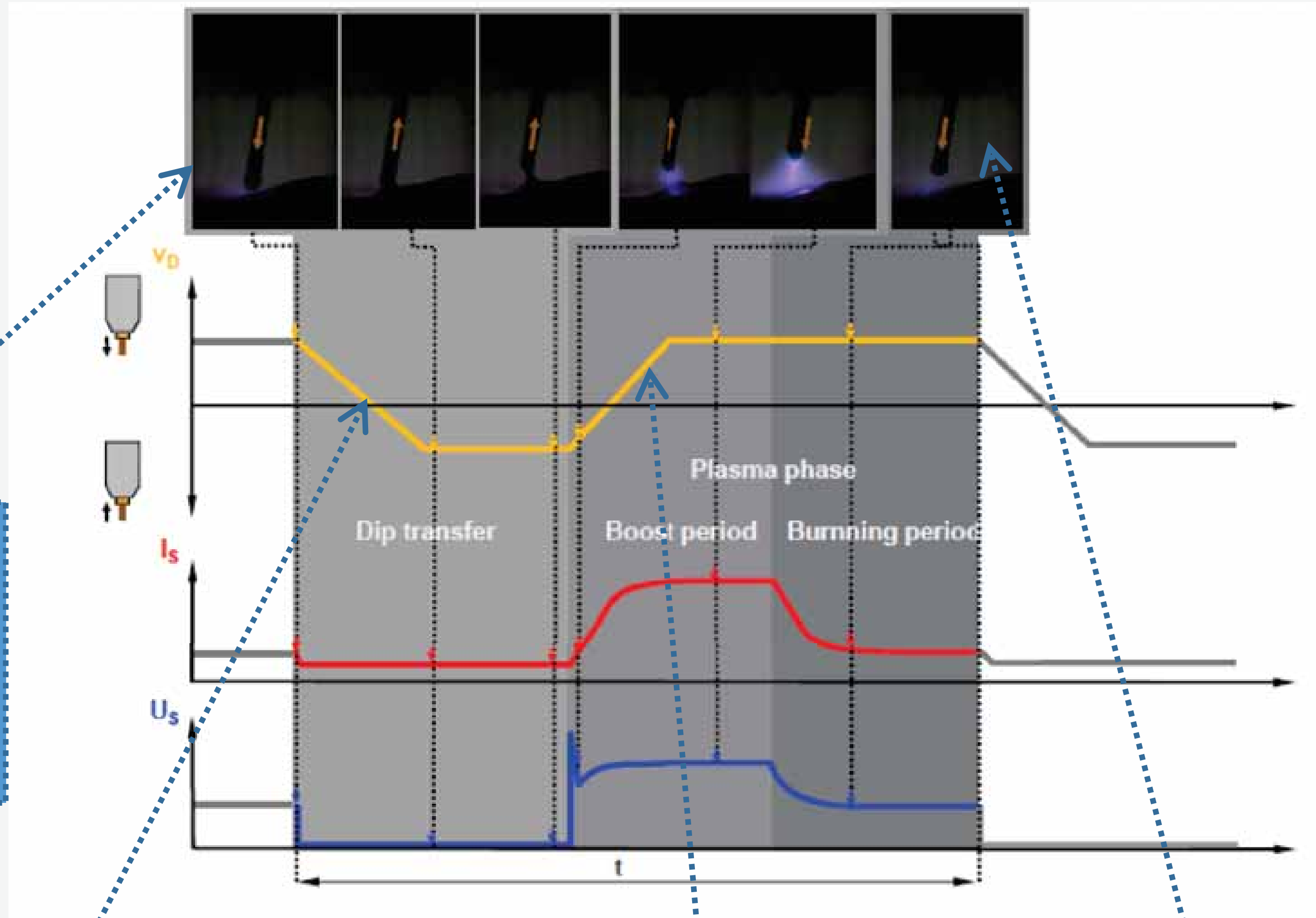
CMT process

Three main variables on CMT process:

1. Wire movement direction, V_D
2. Current, I_S
3. Voltage, U_S



When wire hits the melt pool (short circuit), arc diminishes, and welding current level lowered

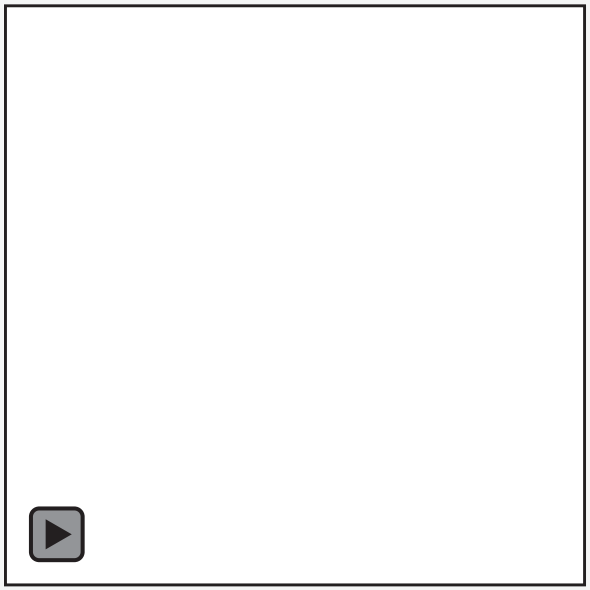
Wire retraction starts that helps to loose melt drop from the tip of the wire

During the arc phase, wire is moved towards melt pool.

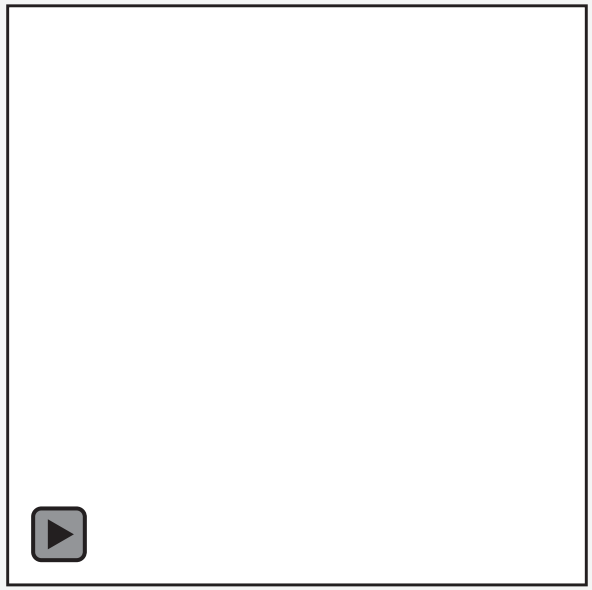
Current and voltage values are lowered and wire starts to reach the melt pool

Standard MIG, pulse MIG and CMT processes

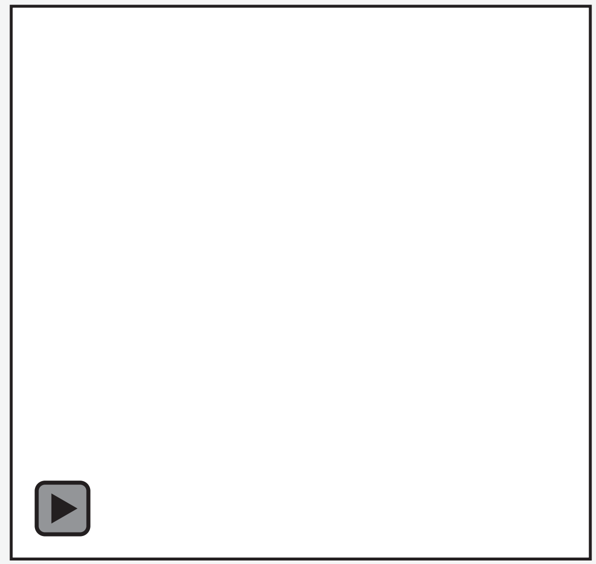
High speed videos from three processes: standard MIG/MAG, Pulse MIG/MAG and CMT



MIG/MAG short arc process: Occasional short circuiting and spattering [Fronius GmbH, Pronius Oy]



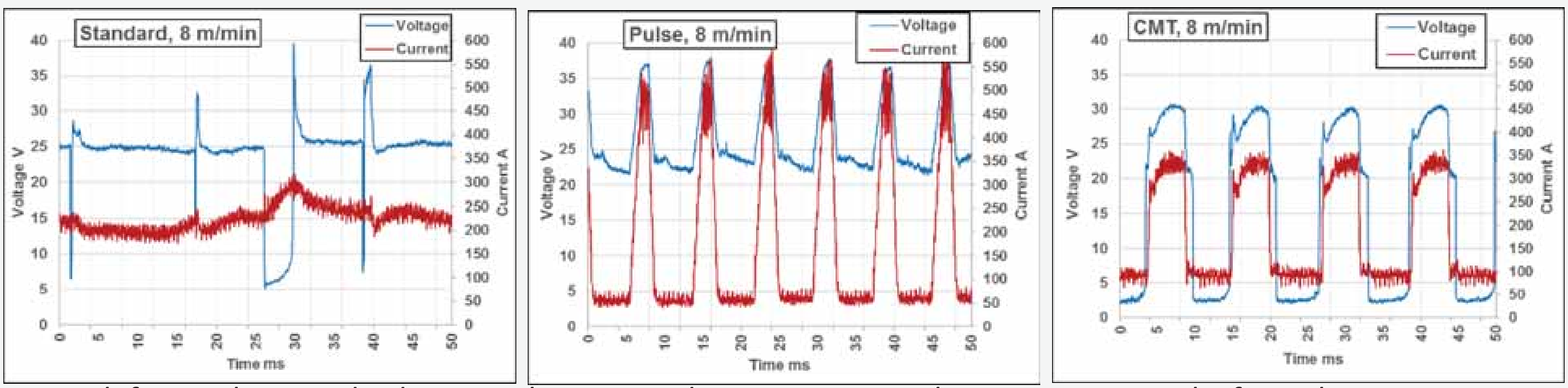
Pulse MIG process: Cyclic arcing and material transfers in droplets during arcing phase. [Kemppi Oy, Youtube]



CMT process. Cyclic short circuiting and arcing. Material transfers during short circuit phase. No spattering. [Fronius GmbH, Pronius Oy]

Standard MIG, pulse MIG and CMT processes

- Oscilloscope graphs during the process were determined with three processes: standard MIG/MAG (S538), Pulse MIG/MAG (P327) and CMT (C1693).
- Wire feed speed 8 m/min, single bead on plate, Ø1,2 mm alloy 625 wire, travel speed 1000 mm/min, shield gas Ar-30%He, mild steel substrate (20 mm).
- Current and voltage waveform is <u>irregular</u> in standard MIG process.
- Current and voltage waveform is very <u>regular</u> on both pulse and CMT processes.



From left to right: Standard MIG, Pulse MIG and CMT process. Voltage-current graphs from the oscilloscope, WFS: 8 m/min

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Surface cleaning - bead surface appearance

- Images from single bead tests with standard MIG, Pulse MIG and CMT process
- Arc cleaning effect can be seen also with other processes, but CMT is cleaner, clearly less black deposit compared to standard and pulse processes

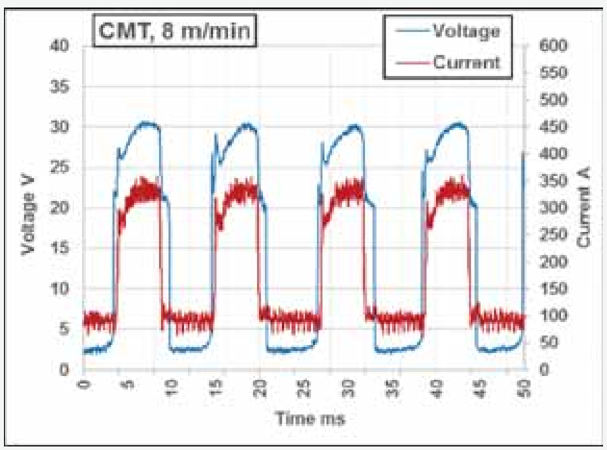
Standard 4, 5, 6, 7 and 8 m/min

Pulsed 4, 5, 6, 7, 7 and 8 m/min

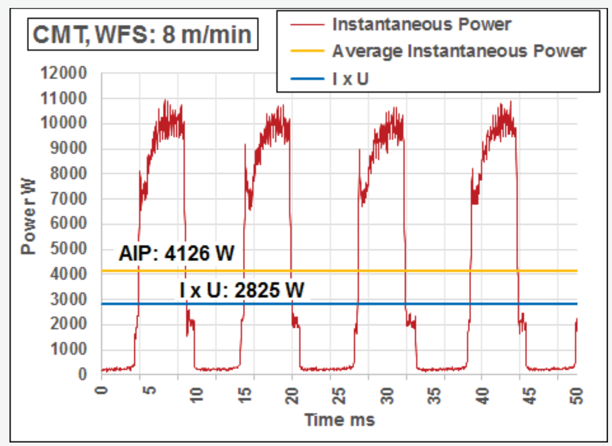
CMT 5, 6, 7, 8, 9 and 10 m/min

The determination of arc power

- Traditionally, arc power is determined by multiplying average current and voltage (I x U) during the process.
- According to new standards ISO 15614-1 and ISO/TR 18491, arc power during welding process should be measured using so called Average Instantaneous Power (AIP) method.
- In this method, current and voltage are measured with high frequency (>1000 Hz) and multiplied with each other on each moment of time. AIP value is an average of these results.



$$AIP = \frac{\Sigma_i^n U_i \times I_i}{n}$$



Average voltage from welding power source: 15,5 V
Average current from welding power source: 182 A
→ U x I = **2825 W**

Average voltage meas. with oscilloscope: 15,6 V
Average current meas. with oscilloscope: 186 A
→ U x I = 2901 W

AIP = 4126 W

AIP 46% larger compared to U x I power 2825 W

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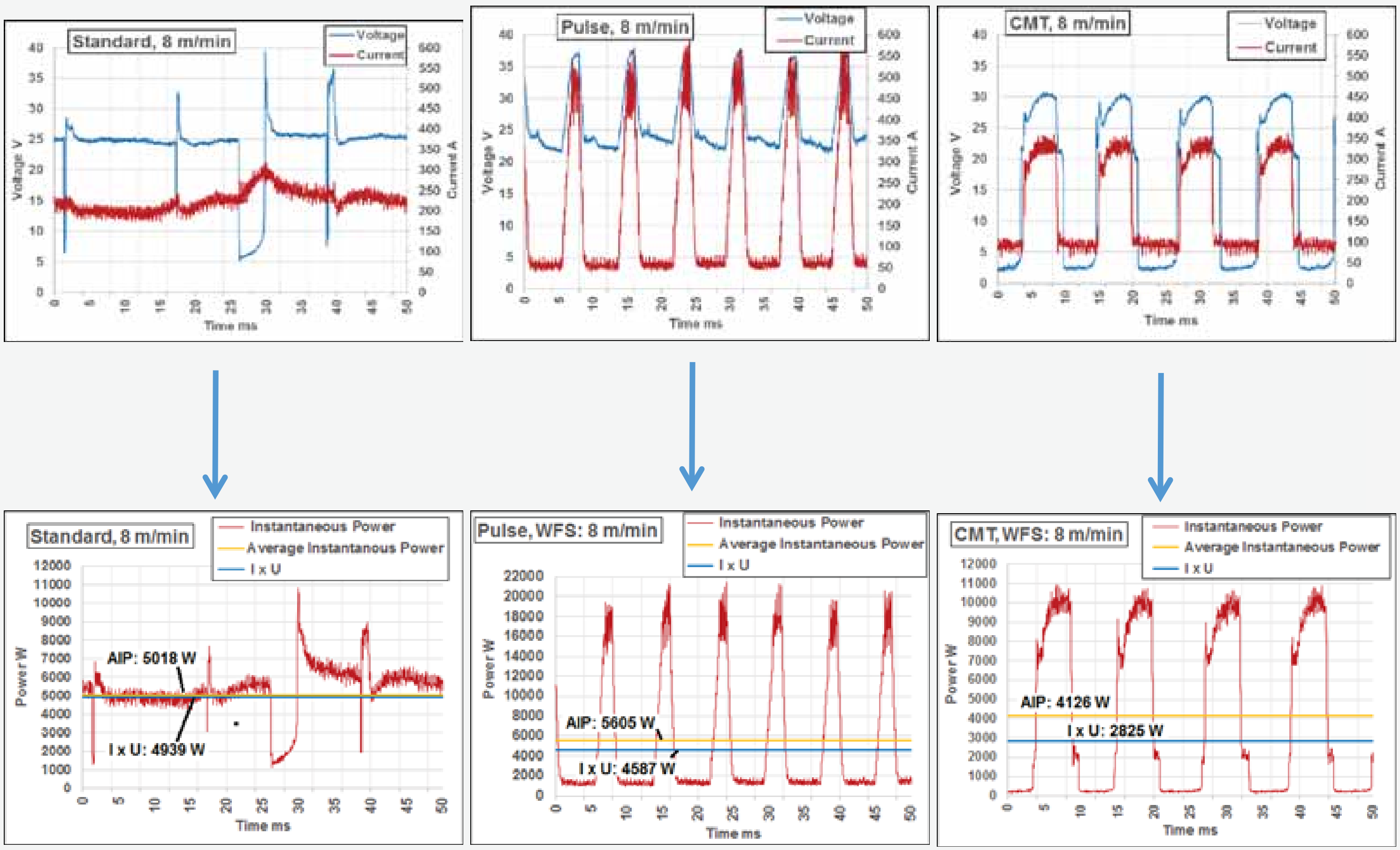
Arc power - standard MIG, Pulse MIG and CMT

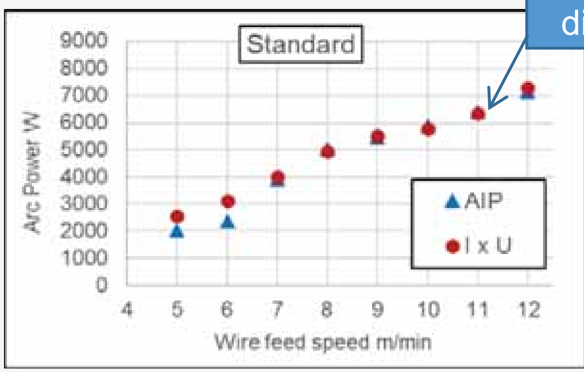


From left to right: Standard MIG, Pulse MIG and CMT process. Arc power graphs. Power determined with Instantaneous Power (IP), AIP and I x U methods.

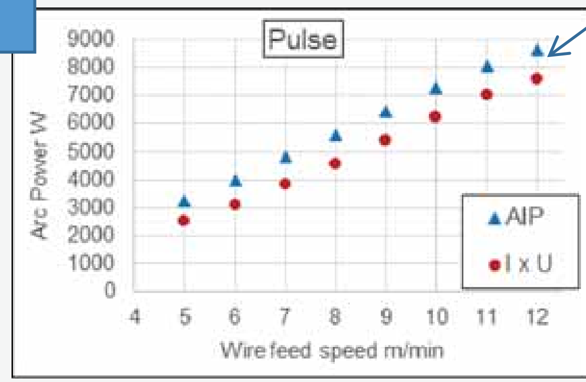
Arc power - standard MIG, Pulse MIG and CMT

- Results show that:
  - With standard MIG process, both traditional I x U and AIP method gave the same result.
  - With Pulsed MIG and CMT process, AIP method gave higher results compared to I x U method.
  - With CMT this difference was large, between 30 – 45%.

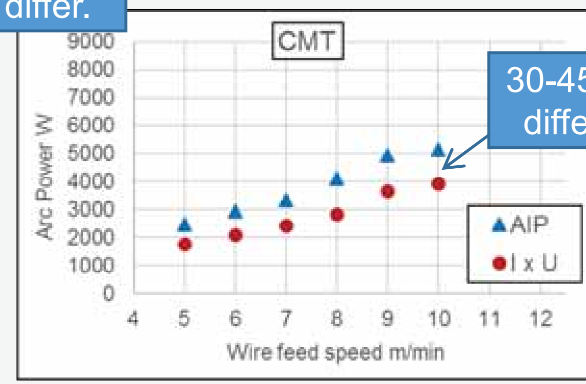
- Results are published in Hitsaustekniikka journal 6/2017.



WFS m/min	Average I and U			Oscilloscope			diff:
	I_{mean} A	U_{mean} V	U x I W	I_{mean} A	U_{mean} V	AIP W	I x U vs. AIP
5	122	20.9	2538	125	18.9	2019	-21 %
6	130	24.1	3124	136	20.0	2346	-25 %
7	184	21.7	4007	185	21.9	3922	-2.1 %
8	203	24.4	4939	204	24.6	5018	1.6 %
9	214	25.8	5511	218	25.1	5462	-0.9 %
10	229	25.3	5793	230	25.6	5885	1.6 %
11	243	26.1	6354	242	26.4	6399	0.7 %
12	265	27.5	7277	262	27.3	7139	-1.9 %



WFS m/min	Average I ja U			Oscilloscope			Diff:
	I_{aver} A	U_{aver} V	U x I W	I_{aver} A	U_{aver} V	AIP W	I x U vs. AIP
5	105	24.0	2508	107	24.2	3271	30 %
6	128	24.3	3102	129	24.7	3970	28 %
7	153	25.2	3846	155	25.7	4800	25 %
8	175	26.3	4587	178	26.8	5605	22 %
9	197	27.3	5374	200	27.8	6419	19.4 %
10	223	28.0	6247	227	28.4	7278	16.5 %
11	240	29.2	6996	243	29.8	8081	15.5 %
12	261	29.0	7567	262	29.8	8661	14.5 %



WFS m/min	Average I ja U			Oscilloscope			Diff:
	I_{aver} A	U_{aver} V	U x I W	I_{aver} A	U_{aver} V	AIP W	I x U vs. AIP
5	123	14.5	1784	126	14.4	2474	39 %
6	139	15.3	2115	141	15.3	2936	39 %
7	153	15.9	2437	155	15.8	3333	37 %
8	182	15.5	2825	186	15.6	4126	46 %
9	205	17.9	3665	207	18.0	4946	35 %
10	218	18.1	3928	219	17.8	5134	31 %

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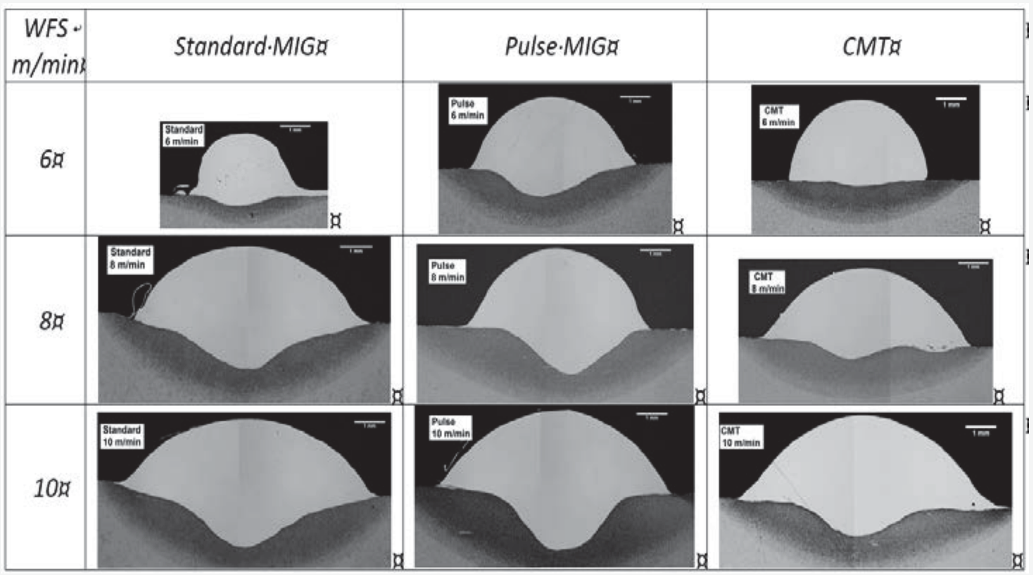
Arc power - standard MIG, Pulse MIG and CMT

- Conclusion: arc power, or heat input on CMT process is smaller compared to standard MIG and Pulse MIG processes, but the actual arc power is larger than it appears to be based on average current and voltage.
- Newest welding power sources (Fronius TPS/i, Kemppi X8) calculate arc power based on the same AIP method, since controlling software measures current and voltage with high frequency anyway. This change has came due to changes in standard requirements (ISO 15614-1)



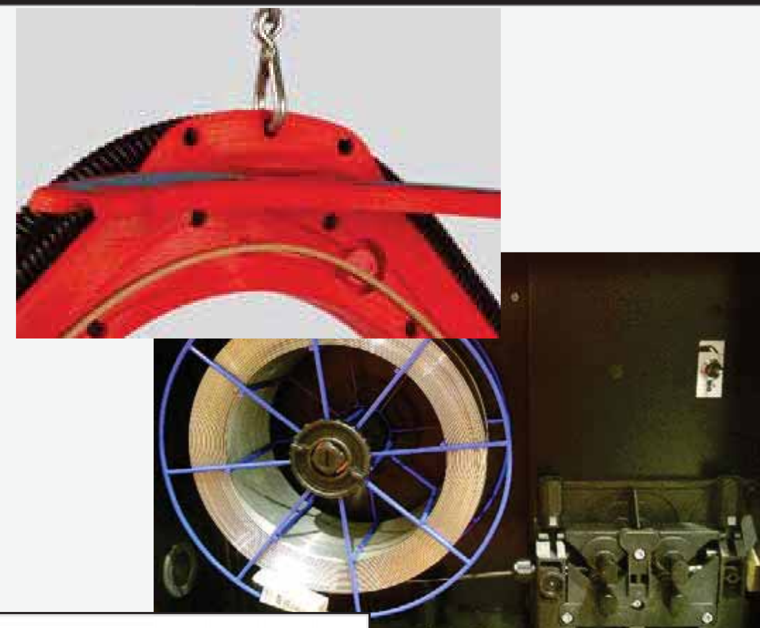
Alloy 625 single bead on plate cross sections with three processes with WFS of 6, 8 and 10 m/min.

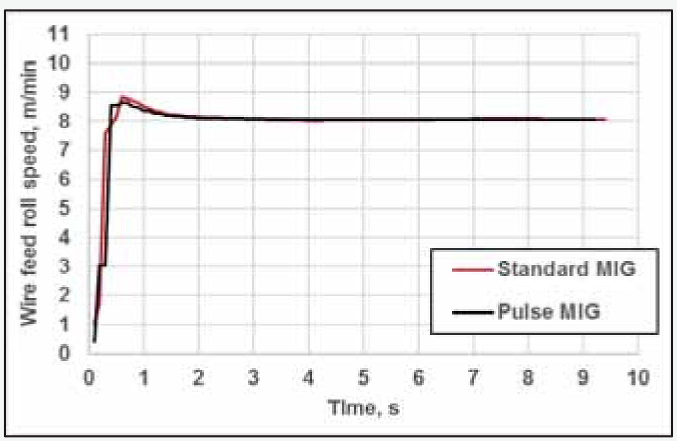
Results with WFS 8 m/min

Parameter	Standard MIG	Pulse MIG	CMT
Average voltage	24.4 V	26.3 V	15.5 V
Average current	203 A	175 A	182 A
Arc power, I_{aver} x U_{aver}	4939 W	4587 W	2825 W
AIP	5018 W	5605 W	4126 W
Actual fire feed rate	8.1 m/min	8.1 m/min	8.8 m/min
Power ratio	548 W/mm²	612 W/mm²	415 W/mm²
Bead cross section area	9.5 mm²	10.0 mm²	10.4 mm²
Penetration	1.5 mm	1.3 mm	0.5 mm
Graphical dilution	36%	25%	10%
Melted base material + HAZ area	16.2 mm²	16.2 mm²	10.7 mm²

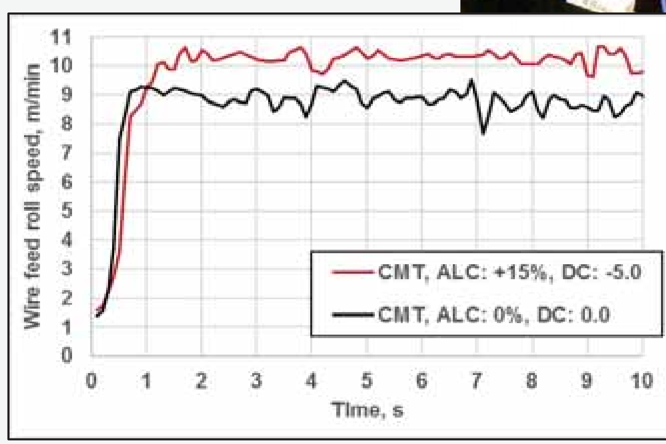
CMT - wire feed rate

- On standard MIG and Pulse MIG processes, wire feed speed (WFS) is stable.
- On CMT process, the actual WFS during process is not as the set one. Actual WFS is stored by Fronius Xplorer software.
- Usually the actual WFS is larger than the set one. For example if the set WFS is 8 m/min, the actual can be 10 m/min. Actual value is depending on auxiliary parameters ALC and DC.





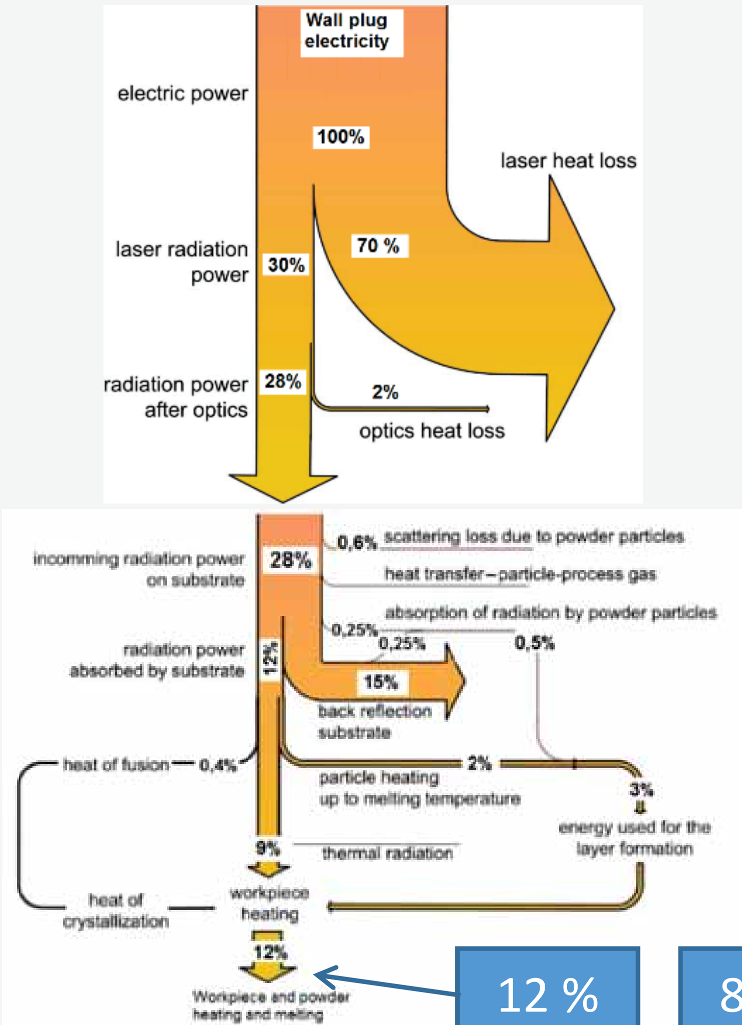
Standard MIG and pulse MIG process. WFS set value 8 m/min. Wire feed roll speed values



CMT process. WFS set value 8 m/min. Wire feed roll speed values with ALC: 0 - DC: 0.0 and ALC: +15% - DC: -5.0.

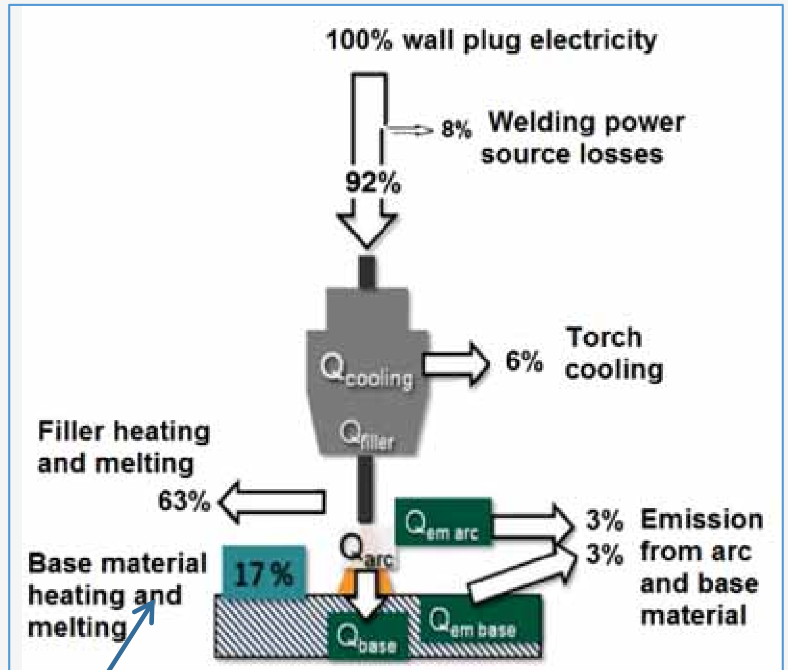
Wall plug electricity efficiency - laser vs. CMT

Laser [Leyens, Brückner, Nowotny]



12 %

CMT [Hälsig & P. Mayr]



80 %

	Total-efficiency
Laser	12%
CMT	80%

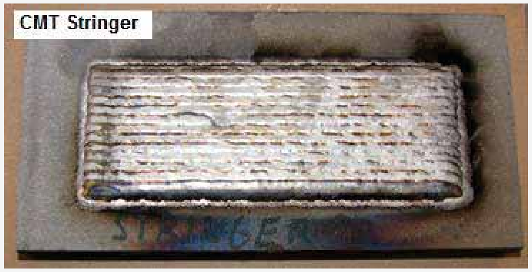
Comparison: alloy 625 laser cladding vs. CMT

- Aims: to compare laser cladding vs CMT cladding process:
  - Heat input to the substrate
  - Productivity and energy efficiency
  - Cladding properties
- Substrate temperature was measured with a one sensor below the last pass.
- To compare CMT process with single (stringer motion) and two wires (TWIN, weave motion).
- Cladding with two wires (TWIN) does not seem to be possible or reasonable on stringer motion

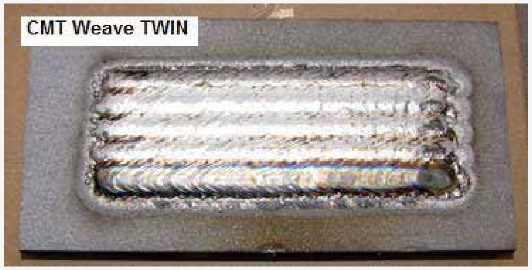
Cladding parameters

	Laser	CMT Single	CMT TWIN
Process set power [1]	4200 W (set)	-	-
Feedstock feed rate	40 g/min	8 m/min	Lead: 8,5 m/min Trail: 8 m/min
Synergy line	-	1693	Lead: 1631 Trail: 1632
Shield gas	100%Ar	Ar-30%He	100%Ar
Motion	Stringer	Stringer	Weave
Weave width	-	-	12 mm
Travel speed	1500 mm/min	1000 mm/min	720 mm/min
Track displacement	1,5 mm	3,8 mm	10 mm
Coverage rate (TSxTD)	0.14 m^2/h	0.23 m^2/h	0,43 m^2/h

Laser cladding.

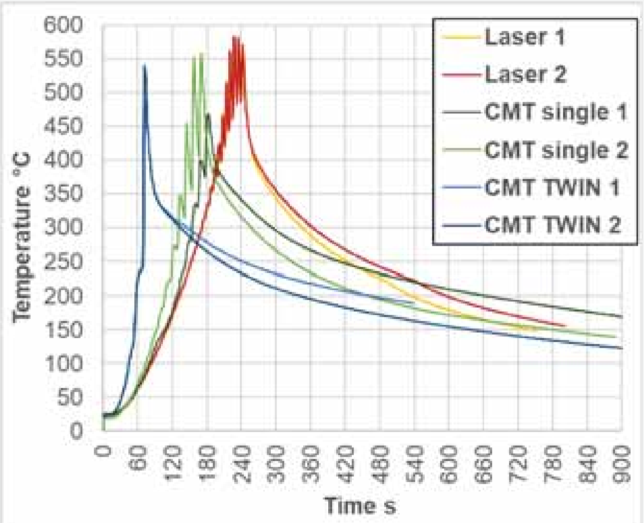


CMT single wire, stringer motion.




CMT TWIN weaving motion. Two wires

Comparison: Alloy 625 with laser and CMT



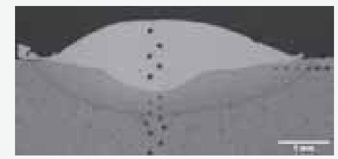
Substrate temperature measur. results

Max temperatures

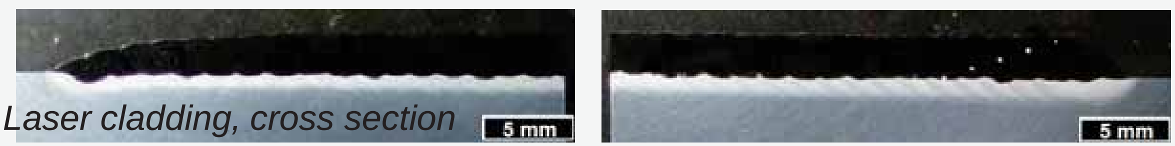
	Laser	CMT single	CMT TWIN
Max temp	1. 580°C 2. 583°C	1. 468°C 2. 560°C	1. 489°C 2. 539°C

Dilution and hardness measurement

Feature	Laser cladding	CMT Single	CMT TWIN
Aver. Hardness (last bead)	234 HV_5	220HV_5	222 HV_5
Fe content	first: 33% last: 8,9%	first: 9,0% last: 7,1%	first: 2,9% last: 1,6%

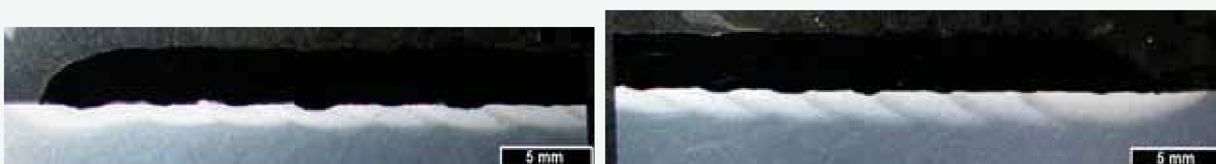


Laser single bead cross section

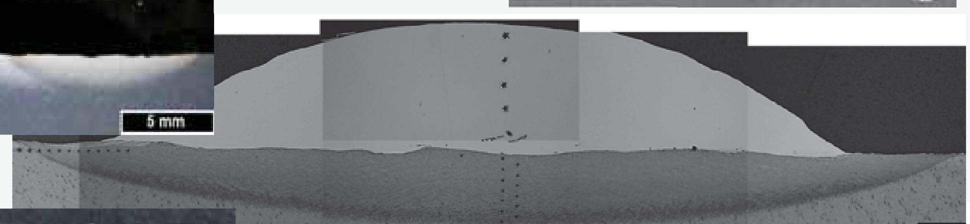


Laser cladding, cross section

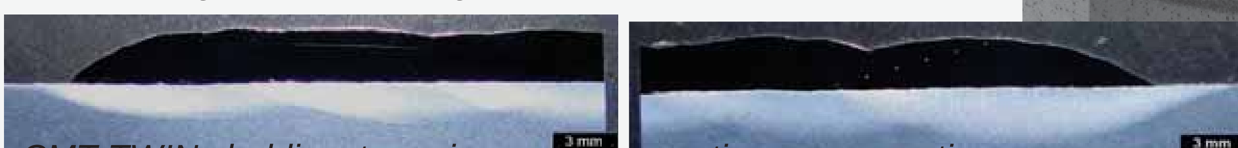
CMT stringer single bead cross section.



CMT cladding, one wire, stringer motion, cross section.



CMT TWIN single bead cross section.



CMT TWIN cladding, two wires, weaving motion, cross section

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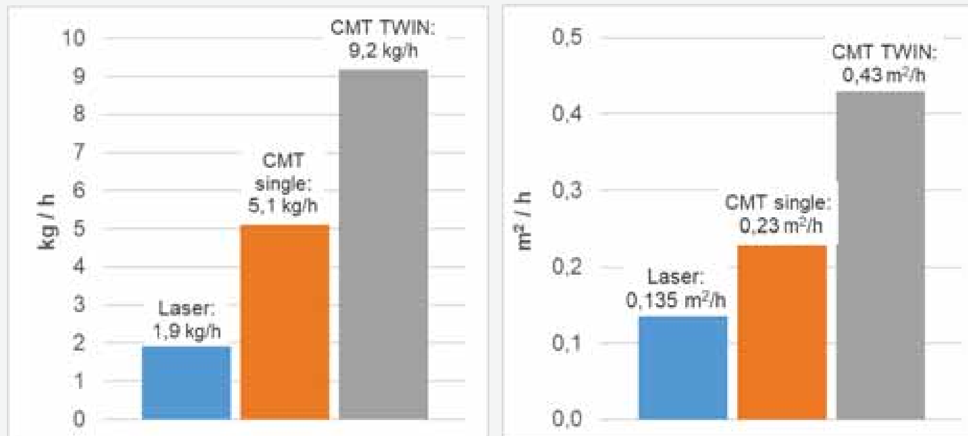
Comparison: Alloy 625 laser cladding vs CMT

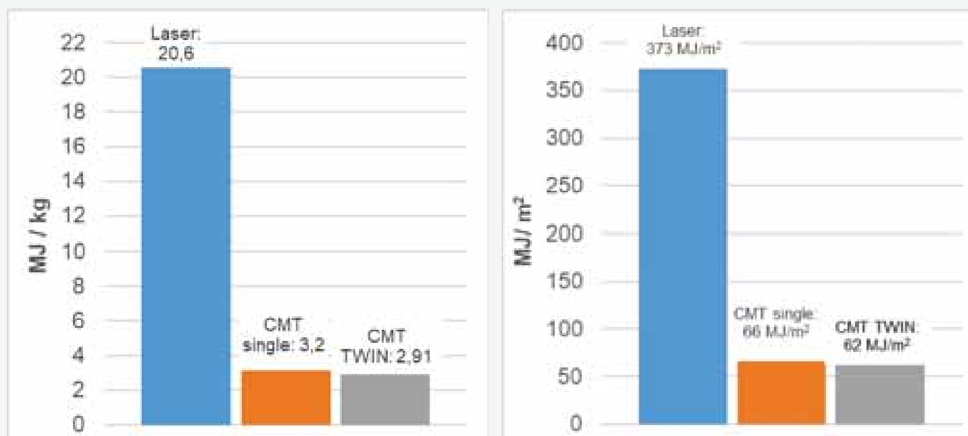
Some cladding results with alloy 625

	Laser cladding	CMT Single	CMT TWIN
Process set power (1)	4200 W (set)	2830 W	5015 W
Actual power (2)	3800 W	3880 W	6870 W
Wall plug power (3)	14 000 W	4220 W	7470 W
Total laser or arc on time	197 s	126 s	62 s
Total cladding time	240 s	170 s	74 s
Energy input (5)	749 kJ	456 kJ	426 kJ
Total energy input (6)	2 760 kJ	496 kJ	463 kJ
Cladding mass	134 g	168 g	160 g
Actual feedstock feed rate (7)	41 g/min, 2.4 kg/h	83 g/min, 4.8 kg/h	159 g/min 9,3 kg/h
Total energy consumption per m^2 of cladding	373 MJ/m^2 104 kWh/m^2	66 MJ/m^2 18.4 kWh/m^2	62 MJ/m^2 17,3 kWh/m^2
Total energy consumption per kg of cladding	20.6 MJ/kg 5.7 kWh/kg	3.2 MJ/kg 0.88 kWh/kg	2,9 MJ/kg 0,81 kWh/kg

1) Laser: Set power, CMT: average current x voltage, average value of two tests
2) Laser: estimated power on work piece. CMT: AIP
3) Laser: 30% efficiency, CMT: 92% efficiency (vs. AIP)
5) Actual power x laser or arc-on time
6) Actual wall plug power x arc-on time
7) Calculated from cladding mass vs actual arc on time



Cladding deposition rate, kg/h (left) and cover rate, m^2/h (right).



Cladding energy consumption, MJ/kg (left) and MJ/m^2 (right).

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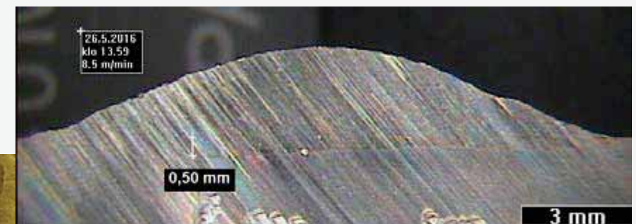
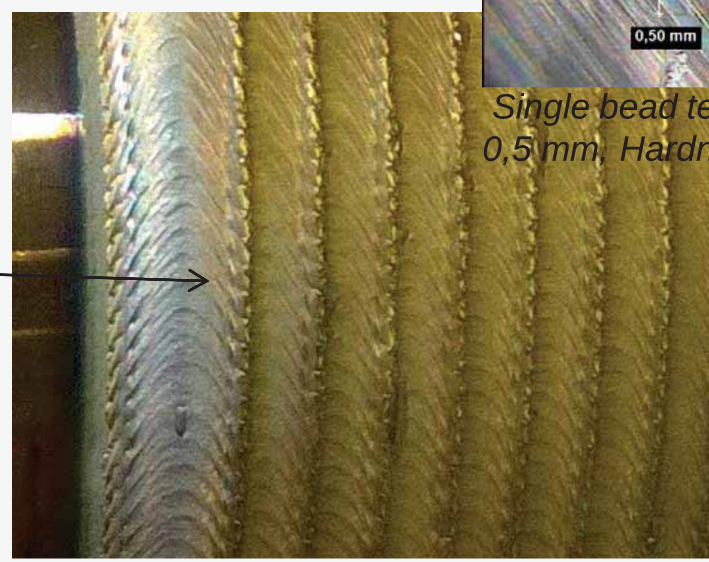
CMT cladding of large diameter tube with 316 SS

- Shaft diameter: Ø320 mm.
- Wall thickness: 20 mm.
- 316LSi wire, Ø1,2 mm.
- Weaving motion, width: 12 mm
- Travel speed: 8 mm/s (480 mm/min)
- Track displacem.: 10 mm
- Cover rate: 0,288 m²/h. (TS x TD)

- Wire feed speed: 8,5 m/min.
- Deposition rate: ~5 kg/h.
- Current: 200 A
- Voltage: 15 V
- Arc Power: 3000 W
- Coating thickness: ~2,5 mm



Single bead test cladding. Penetration 0,5 mm, Hardness: ~170 HV5.



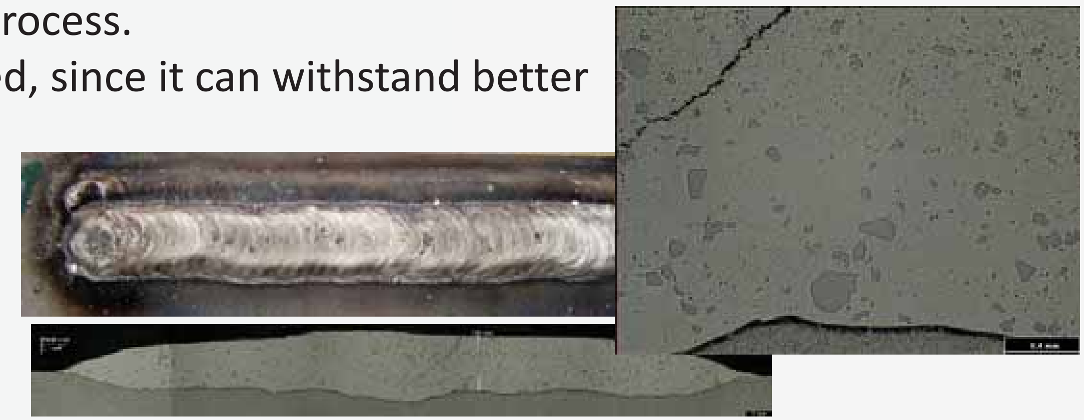
Cladding of large diameter tube

Cladding of large diameter, thin walled tube with 316L SS.

Video through the welding shield glass.

CMT results: Ni-WC wire, Ø1,2 mm

- Ø1,2 mm cored wire Corocarb Ni .
- Ni-Cr-B-Si matrix, angular-shaped tungsten carbides (WC)
- Tests were made both with pulse and CMT process
- Low arc power and heat input is essential in order to keep the large, primary tungsten carbides dissoluted during the process.
- Relatively soft and ductile matrix is desired, since it can withstand better residual stresses and impacts.

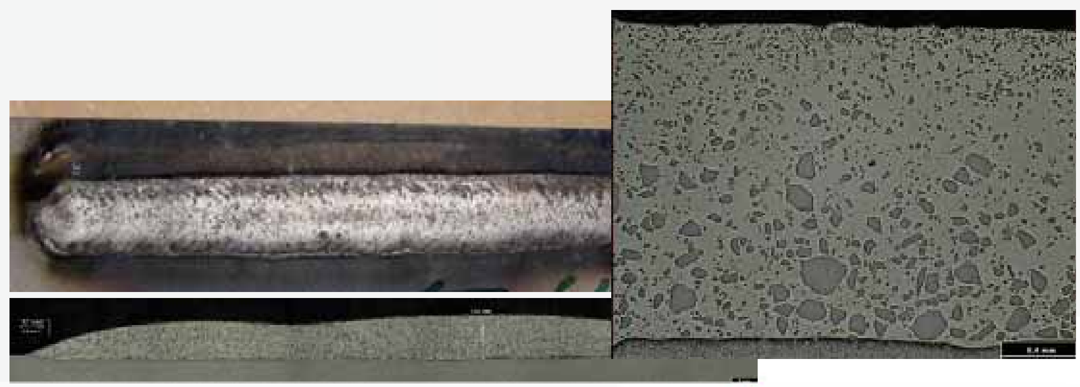


Pulse process. Cracks, high dilution, carbides more melted.

Some parameters (successful tests):

- Shield gas: Ar-18%CO_2
- WFS: 6 m/min
- Travel speed: 6 mm/s
- Weave width: 12 mm
- Frequency: 2 Hz
- Cover rate: 0,22 m^2/h
- Deposition rate: 2,8 kg/h

Process	Synergy line	Current A	Voltage V	Arc power W	Matrix hardness
Pulse	79	156	19,7	3070	min: 374 HV1 max: 529 HV1 aver: 456 HV1
CMT	1657	169	13,5	2280	min: 403 HV1 max: 443 HV1 aver: 424 HV1



CMT process. No visible cracks, very low dilution, carbides less melted.

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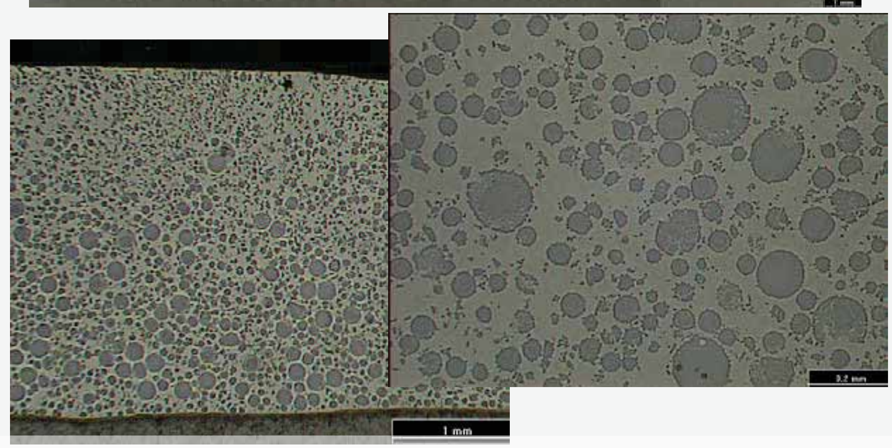
CMT results: Ni-WC wire, Ø1,6 mm

- Ø1,6 mm cored wire NiFD Plus.
- Ni-Cr-B-Si matrix, globular-shaped tungsten carbides.
- Low arc power and heat input is essential in order to keep the large, primary tungsten carbides dissoluted during the process.
- Tests were made with CMT process



No visible cracks on outer surface, but some in cross section very low dilution, large amount of primary carbides left in the structure.

Some parameters (successful tests):

• Synergy line: 1732	
• Shield gas: Ar-18%CO_2	
• WFS:	4,5 m/min
• Travel speed:	3 mm/s
• Weave width:	12 mm
• Frequency:	2 Hz
• Cover rate:	0,11 m^2/h
• Deposition rate:	4,5 kg/h
• Matrix hardness:	580 HV
• Current:	216 A
• Voltage:	14,6 V
• Arc Power:	3150 W

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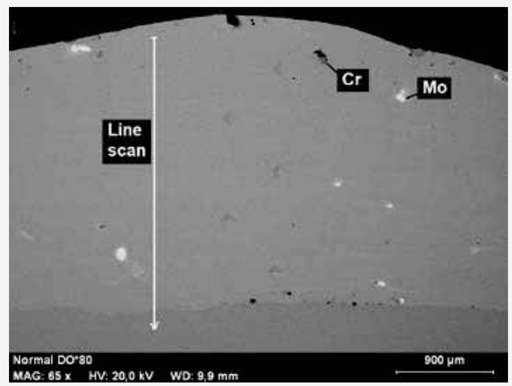
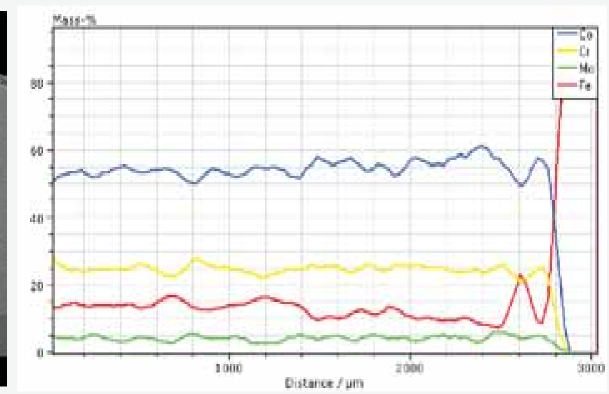
CMT results: Stellite 21 cored wire

- Stellites are expensive to produce as a solid wire, so cored wire is the only option in practice.
- Productivity is good and dilution on low level,
- Large Cr and Mo particles inside the wire remain unmelted in the weld deposit.
- This affects both on corrosion resistance and hardness.
- On laser cladded stellite 21, hardness is around 400 HV and structure is homogeneous.

Cored wire	ø1,6 mm
Synergy line	1592
Shield gas	Ar + 2%CO_2
Travel speed	6 mm/s
Weaving	12 mm
Frequency	2 Hz
WFS	6 m/min

Deposition rate*	5,1 kg/h
Cover rate	0,22 m^2/h
Current	262 A
Voltage	14,5 V
Arc power (I x U)	3900 W
Hardness	**336 HV**





SEM image and EDS line scan. Fe: 7 – 17% to the depth of 2,5 mm.

Ø1.6 mm Stellite 21, cross section of the wire. SEM BE image and EDS mapping images for elements: Cr, Mo and Ni. Not any large Mo particles (in the middle) can be seen.

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CMT results: other filler materials

Material	type	Results, briefly
Duplex stainless steel 22-9-3	solid	Works fine
Aluminium bronze, CuMn13Al8Fe3Ni2	solid	Works fine, very low dilution hardness: ~280 HV
Martensitic 0,4%C - 9%Cr wires,	solid	Works, moderate dilution (>20%), hot cracks
Manganese SS, Corodur 250K	cored	Did not work on CMT process
Fe-based hardf., Castolin EG8336	cored	Works fine, high hardness (800 – 900 HV), cracking
Fe-based hardfacing, Corthal 498 G	cored	Works with lower WFS
Fe-based hardfacing, Corodur 580 G	cored	Works fine, crack free, hardness 550 – 600 HV
Fe-based hardfacing, Corodur 600 G	cored	Works fine, but cold cracking
Fe-based hardfacing, Durmat FD 65	Cored, gas-free	Works, but cold cracking

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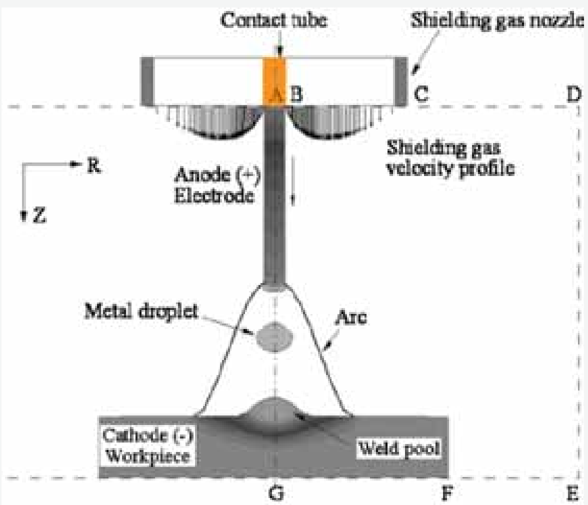
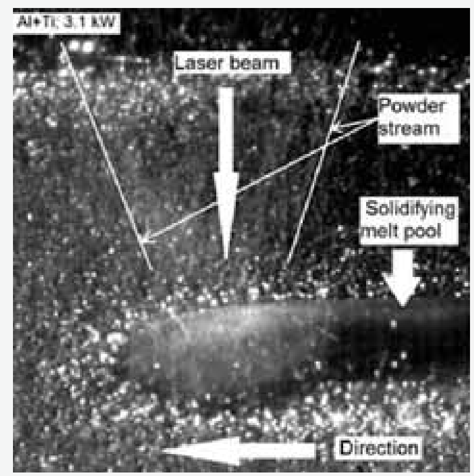
Fundamentals - surface cleaning, laser vs. CMT

- Surface cleaning effect of electric arc is considered to be important on aluminium welding. This happens when electrode is on positive pole.
- This same happens also on CMT process on steel surface and is illustrated on the figures below. This bright area around the melt pool can be seen also when watching welding with glass-shielded eye.
- On laser cladding laser beam hits straight to the melt pool surface and not any cleaning effect does not exist.



A schematic representation of a GMAW system including the electrode, the arc, and the weld pool (not to scale). [Hu & Tsai]

Cleaning effect on MIG/MAG surface welding on steel using positive electrode [GSI SLV G1].



High speed video image capture form single bead laser cladding process [Näkki et al.].

Fundamentals - surface cleaning on CMT

On a CMT process:

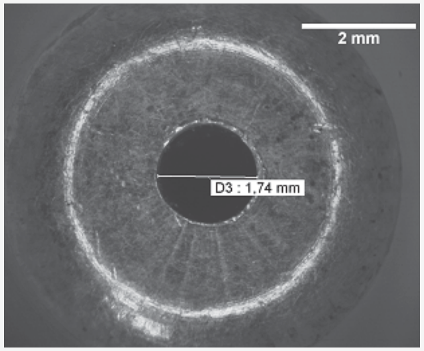
- Electric arc is ignited on each cycle (not necessarily on conv. short circ. process)
- If frequency is 70 Hz and welding speed 16,7 mm/s, welding site moves ~0,2 mm on each cycle.
- Arc gets relatively long due to the fact that wire is retracted from the melt pool.
- Longer arc means that the cathode cleaning area is relatively large.
- Cathode cleaning effect cleans, heats up and prepares the substrate material surface ahead of the melt pool → Cladding is possible with zero penetration, but without lack of fusion between cladding and substrate.

CMT: Drawbacks

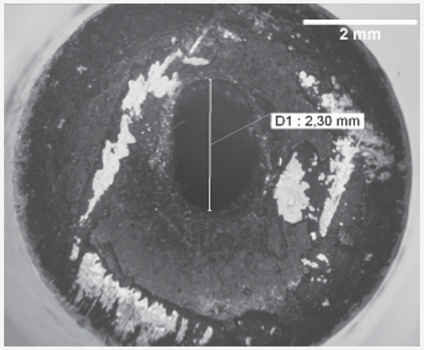
- Minimum achievable layer thickness is ~2 mm.
- Cored wires are designed for hotter spray transfer processes - particles inside the wire a wholly melted.
- Cored wires seem to produce larger penetration and dilution compared to solid wires.
- Spatters in gas nozzle.
- Wear of components: contact tip, pulsating rolls and wire liner.
- Method has not been proved to work on long run, several hours uninterrupted.

Gas nozzle after 80 – 90 min of cladding with 316L wire.

Gas nozzle after 50 min of cladding with iron based hardfacing cored wire.



Unused contact tip.

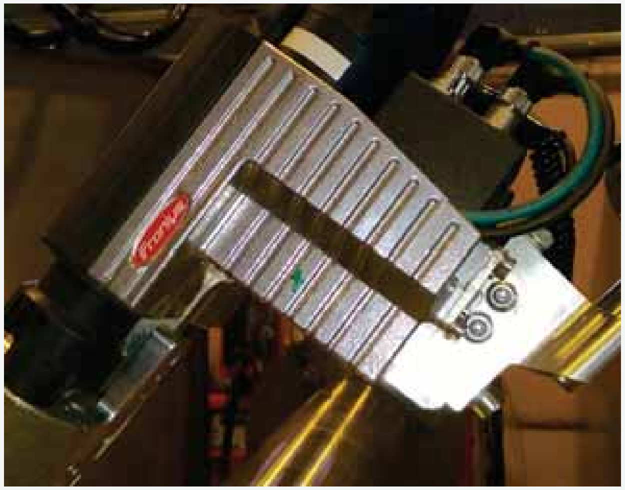


Contact tip after 80 – 90 min of cladding with 316L wire.

CMT: Problems – pulse motor overheating

- On longer test runs pulse motor inside the Robacta drive motor was overheated and welding was interrupted after ~30-40 min of welding.
- This motor rotates the pulsating rolls in the torch.
- The origin of this problem was probably the wrong wire liner material, stainless steel, inside the torch where the wire is moving back and forth. Too much friction between liner and stainless steel wire.

Pulsating rolls



Robacta drive. The location of temperature measurements is pointed with green X-letter. Max surface temperature: 68°C

RCU screen 1 - 2 minutes before the occurrence of “Error in wireweed system PM overcurrent”. Immediately after the error a temperature of 68°C was measured from the surface of Robacta

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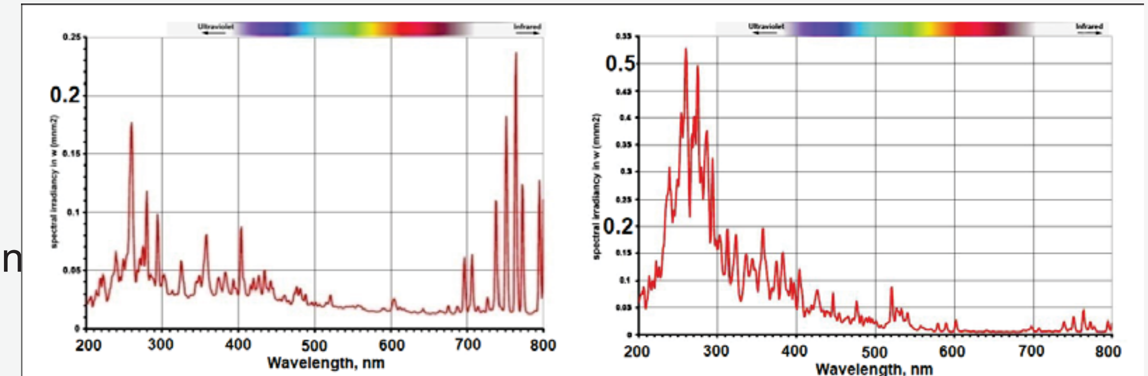
CMT: Drawbacks – UV radiation

- According to some studies radiation on CMT process maybe even higher compared to other similar processes.
- (Marzec, Matusiak) studied the radiation of CMT and ColdArc welding processes on welding X6Cr17 (ferritic) and X5CrN



a TIG welding CrNi of (welding current: 180 A)

b MIG/MAG welding of CrNi (welding current: 180 A)

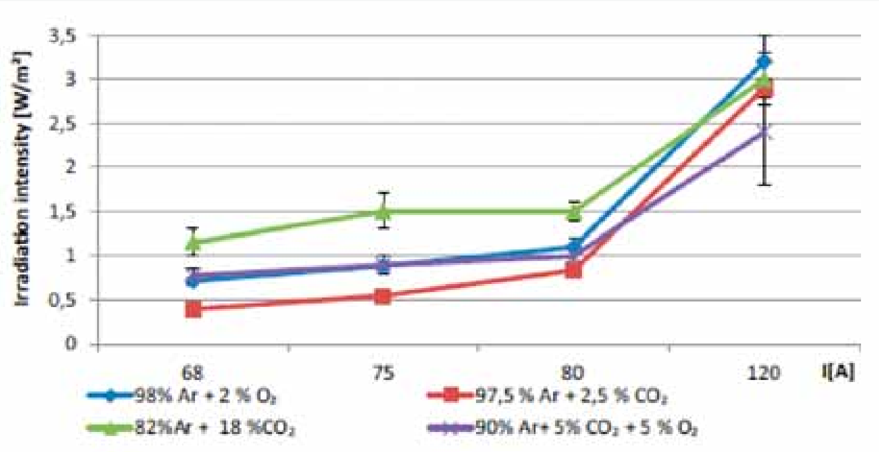
Radiation spectrum of stainless steel with TIG and MIG/MAG processes

Radiation on welding X5CrNi18–10 stainless steel with 97.5%Ar+2.5%CO_2 shield gas [Marzec, Matusiak].

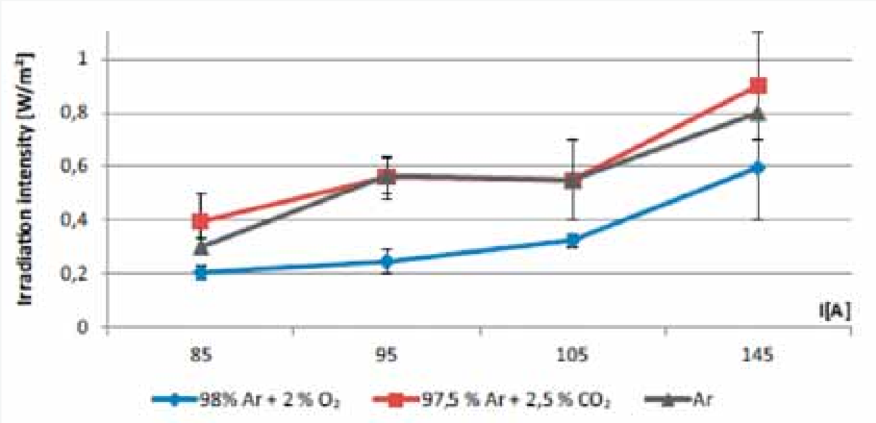
Wire	Shield gas	Process	WFS [m/min]	I [A]	U [V]	UV irradiation intensity [W/m^2]	Blue light radiance [W/cm^2 sr]	IR irradiation intensity [W/m^2]
X5CrNi 18–10	97,5%Ar+ 2.5%CO_2	**CMT**	5,3	121	17,5	**2,40 – 2,60**	4,8 – 6,4	210 - 250
		ColdArc	4,8	145	18,3	0,70 – 1,10	4,9 – 5,4	20 - 100
X6Cr17	82%Ar+ 18%CO2	**CMT**	5,3	120	18,5	**2,7 – 3,3**	20 - 36	60 - 100
		ColdArc	4,8	140	19,9	0,20 – 0,47	19 - 30	60 – 110

CMT: Drawbacks – UV radiation

- Radiation increases strongly as wire feed rate and welding current gets higher



Results of ultraviolet radiation measurements during CMT welding of X6Cr17 (Ferritic) stainless steel in various shielding gases [Marzec, Matusiak]



Results of ultraviolet radiation measurements during ColdArc welding of X5CrNi18– 10 (austenitic) stainless steel in various shielding gases [Marzec, Matusiak]

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Conclusions

- Arc power is lower (and heat isput) on CMT process compared to standard MIG and pulse MIG. However the actual arc power, AIP, is 30-40% higher than determined with standard method I x U.
- Deposition rates with CMT: one wire: 4 – 5 kg/h, two wires: 9 kg/h.
- Minimum achievable layer thickness is ~2 mm.
- Cover rate is around 0,2 m^2/h with one wire and 0,4 m^2/h with two wires.
- Deposition and energy efficiency of CMT is good compared to laser cladding.
- Quality of claddings made with solid wires, like Inconel 625 and stainless steel, is good.
- Stellite coatings with cored wore suffers from unmelted particles and consequently poorer hardness.
- Cladding with tungsten carbide containing hardfacing wires is promising, since carbides remain mainly unmelted.
- UV-radiation of CMT process is on high level. Both eyes and skin needs to be protected and/or welding cell needs to be covered.
- Best results would be reached if the used synergy line is <u>designed especially for the wire</u> and shield gas in use. This applies especially for cored wires.
- Usually weaving motion works better than stringer. CMT process is colder that spray arc or pulsed MIG, so that melt is more sluggish and solidifies faster. As a consequence, with <u>stringer</u> motion melt pool <u>does not spread</u> well and leaves high and narrow reinforcement that makes defect-free cladding with adjacent beads difficult.

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