welding ACADEMY
by voestalpine Böhler Welding

Welding of Duplex & Super Duplex Steels

Advanced – Welding Technology Seminar
Kapfenberg, 23th-26th June 2014

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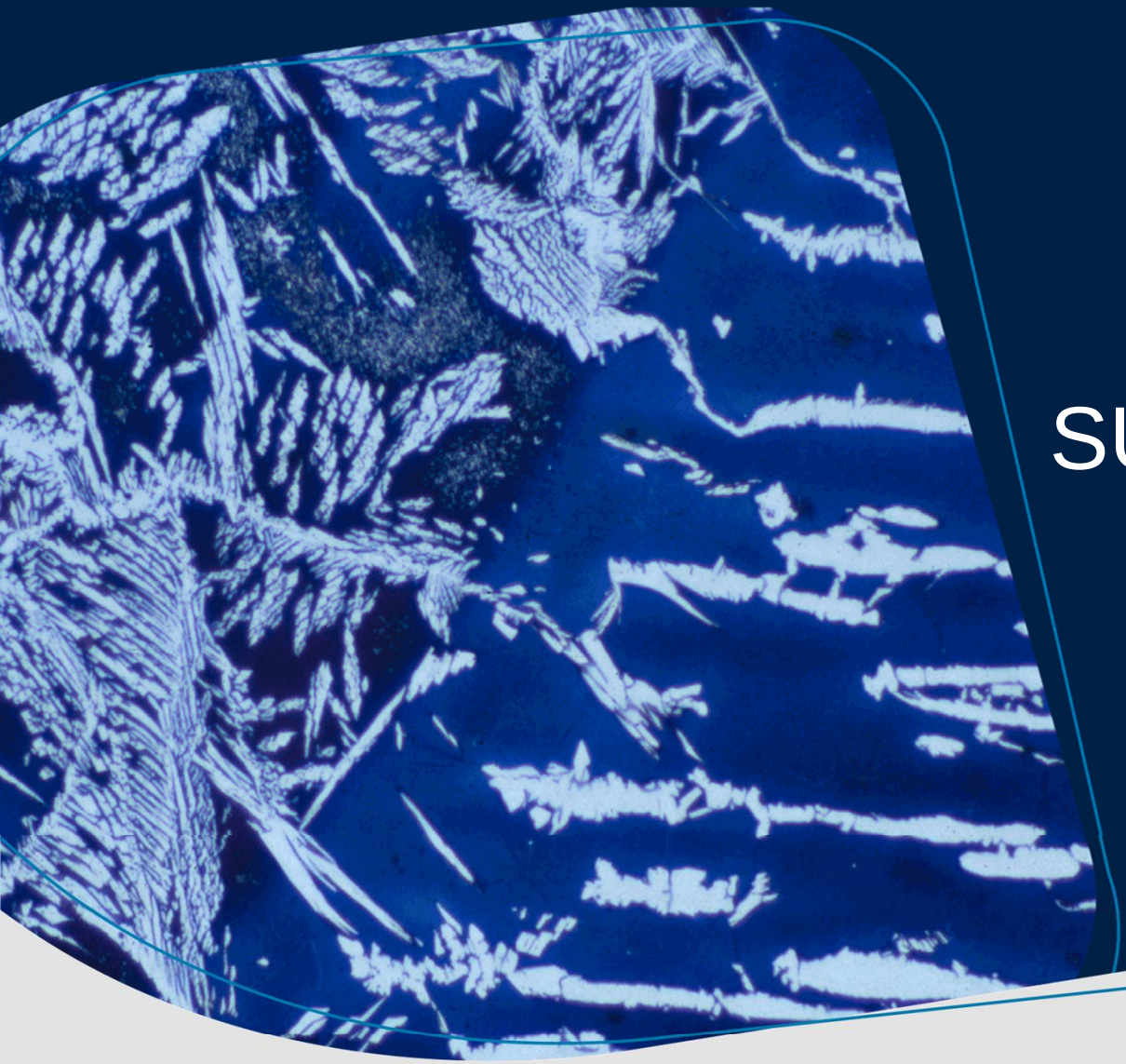

DUPLEX & SUPER DUPLEX

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Alloying with Cr, Ni, Mo, N, etc.

Increase corrosion resistance and improve properties

ASTM	EN	Grade	Cr	Ni	Mo	N	PRE*	$R_{p0.2}$**
304L	1.4307	304L	18.1	8.3	-	-	18	200
316L	1.4404	316L	17.2	10.1	2.1	-	24	220
316L	1.4432	316L hi Mo	16.9	10.7	2.6	-	25	220
904L	1.4539	904L	20	25	4.3	-	34	220
S31254	1.4547	254 SMO	20	18	6.1	0.20	43	300
S34565	1.4565	1.4565	24	17	4.5	0.45	46	420
S32101	1.4162	LDX 2101	21.5	1.5	0.3	0.22	26	450
S32304	1.4362	2304	23	4.8	0.3	0.10	26	400
S82441	1.4662	LDX 2404	24	3.6	1.6	0.27	33	480
S32205	1.4462	2205	22	5.7	3.1	0.17	35	460
S32760	1.4501	Zeron 100	25.4	6.9	3.8	0.27	42	530
S32750	1.4410	2507	25	7	4	0.27	43	530

* PRE = %Cr + 3.3x%Mo + 16x%N, ** Hot rolled plate, min values at 20°C according to EN 10088

Fillers for welding standard duplex

Typical composition (wt-%)

	C	Cr	Ni	Mo	N	Mn
Base material LDX 2101®	**0.03**	**21.5**	**1.5**	**0.3**	**0.22**	**5.0**
SMAW 3D LDX 2101 3D	0.04	23.5	7.0	0.3	0.14	0.7
FCW LDX 2101-PW	0.03	24.0	9.0	0.4	0.13	0.9
Wire LDX 2101	0.02	23.0	7.0	<0.5	0.14	0.5
Base material 2304	**0.02**	**23.0**	**4.8**	**0.3**	**0.10**	**–**
SMAW 2304 3D	0.02	24.5	9.0	-	0.12	0.8
FCW 2304-PW	0.03	24.0	9.0	0.7	0.14	0.8
Wire 2304	0.02	23.5	7.0	<0.5	0.14	0.5
Base material LDX 2404™	**0.02**	**24.0**	**3.6**	**1.6**	**0.27**	**3.0**
SMAW 2404	0.02	24.0	8.5	2.0	0.16	0.7
FCW 2404	0.03	24.5	8.5	1.9	0.16	0.9
Wire 2205	0.02	23.0	8.5	3.1	0.17	1.6
Base material 2205	**0.02**	**22**	**5.7**	**3.1**	**0.17**	**–**
SMAW 2205 3D	0.02	23.0	9.5	3.0	0.15	0.7
FCW 2205-PW	0.03	22.7	9.0	3.2	0.13	0.9
Wire 2205	0.02	23.0	8.5	3.1	0.17	1.6
Base material 2507	**0.02**	**25**	**7**	**4**	**0.27**	**–**
SMAW 2507/P100 3D	0.02	25.5	9.2	3.6	0.24	0.9
FCW 2507/P100	0.02	25.3	9.8	3.7	0.23	0.4
Wire 2507/P100	0.02	25.0	9.5	4.0	0.25	0.4

Pitting resistance lower for welds

Importance of filler metal and welding procedure

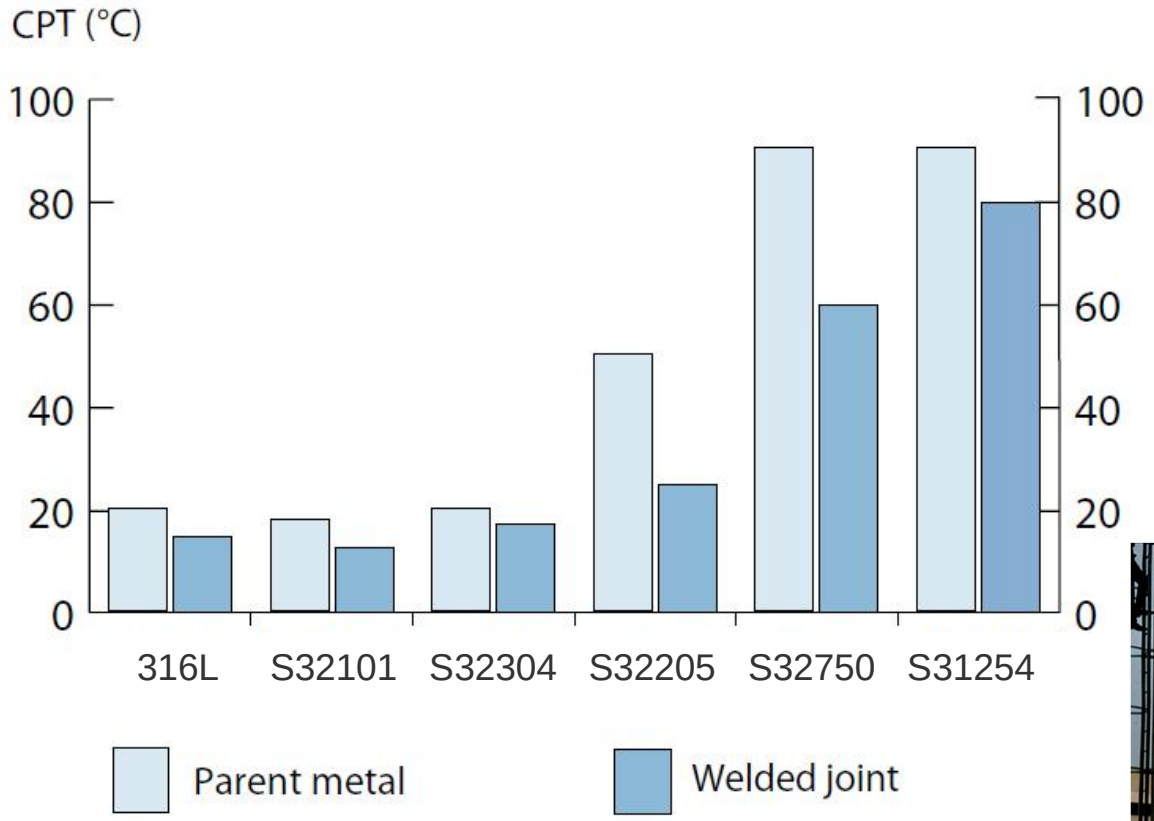
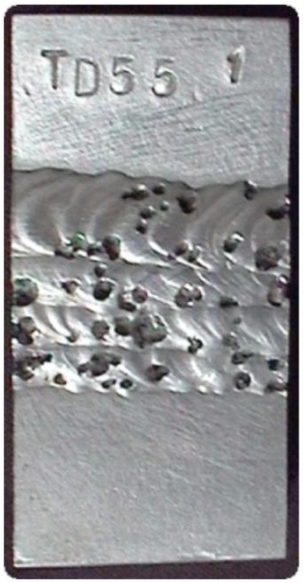
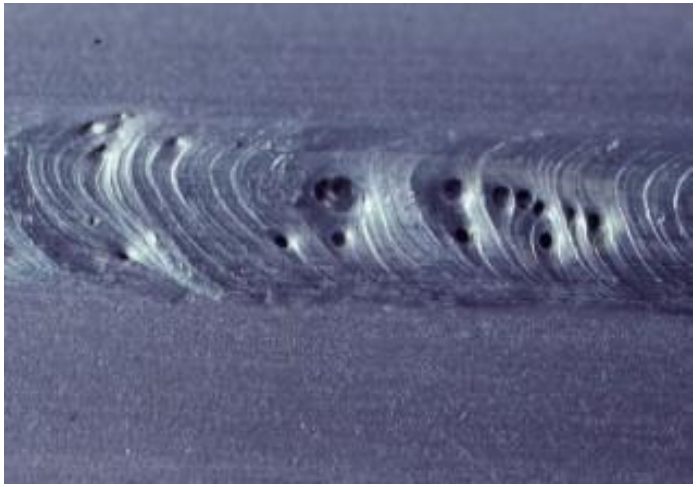


Diagram 1: Typical critical pitting temperatures (CPT) as per ASTM G150 – parent metal and weld, brushed and pickled TIG joint



Effect of welding on corrosion resistance

Welder, welding method and defects



Post fabrication cleaning

For highest possible corrosion resistance

Mechanical methods

- Hand brushing
- S
- G
- P

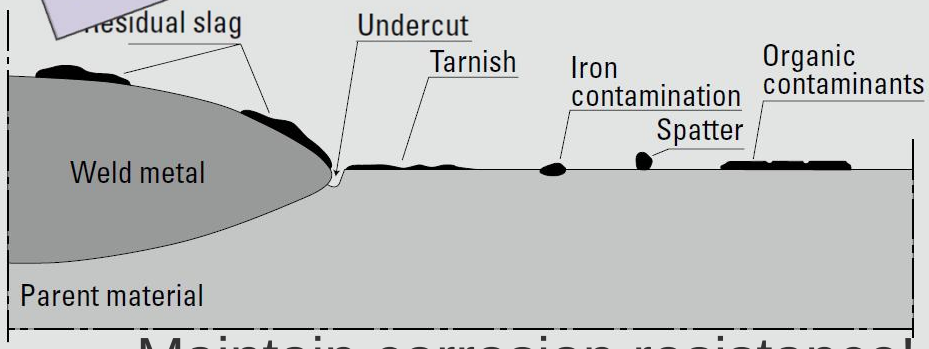
Duplex weld oxide becomes glass-like

Brush welds after cooling

steel

Only use

Brushing with steel brush



Maintain corrosion resistance!

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Cleaning of welds – directly after welding (<100°C)

Makes post-weld cleaning easier and shortens pickling time

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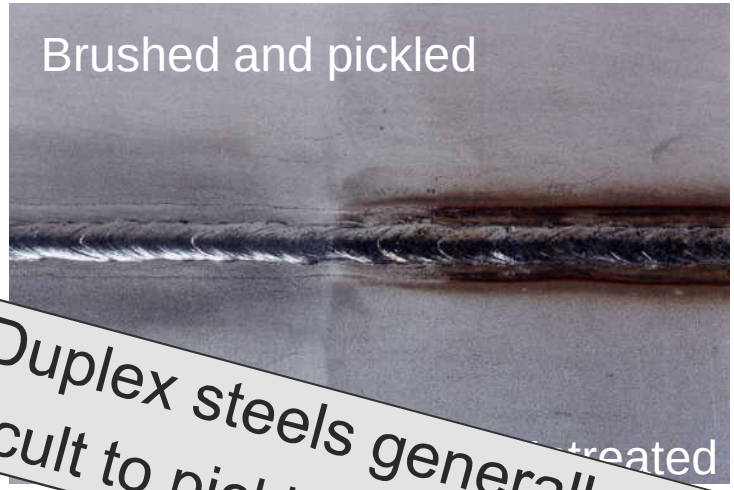
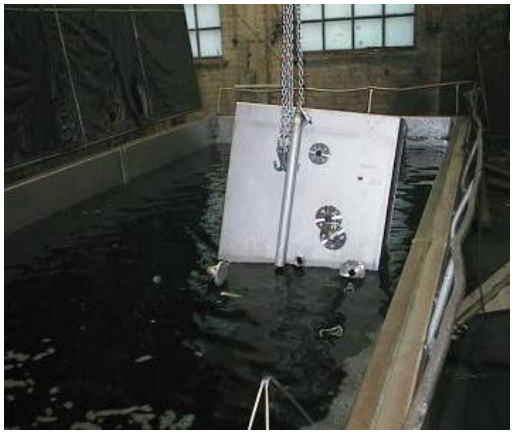
Post fabrication cleaning

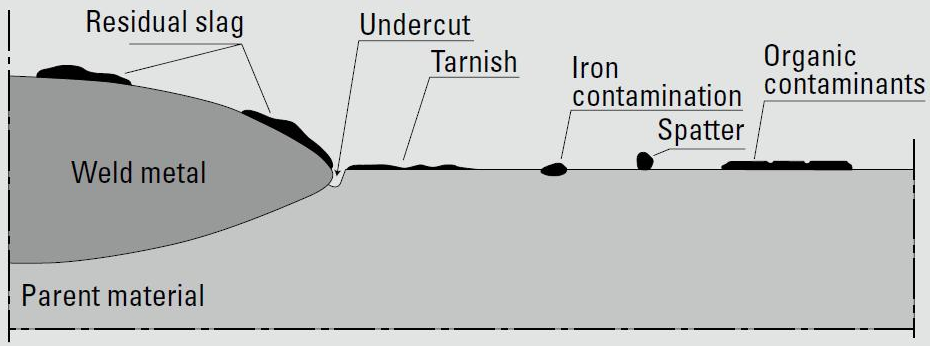
Chemical methods – pickling most efficient

- Degreasing
- Pickling
- Passivation



Duplex steels generally more difficult to pickle than 304 and 316





Duplex microstructure

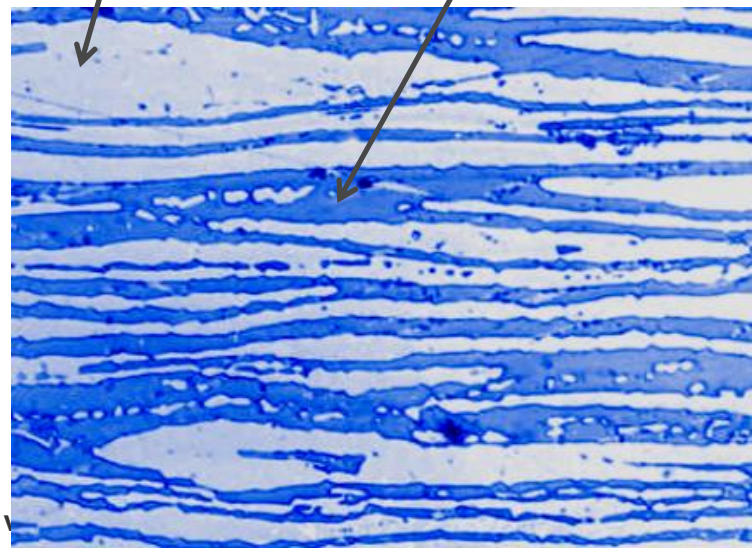
BASE MATERIAL

Controlled cooling

→ 50% ferrite

White = austenite

Blue = ferrite



WELD METAL

Welding method

Base metal composition

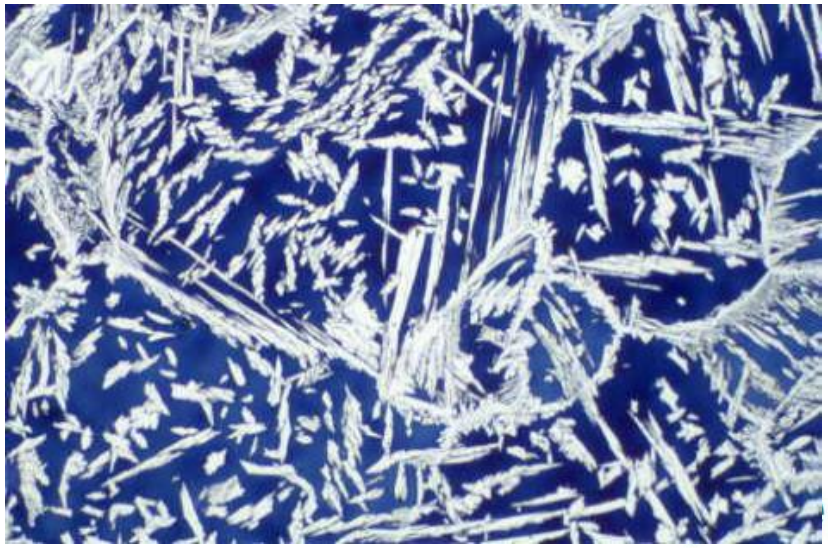
Material thickness / bevelling

Filler metal composition

Shielding / backing gas

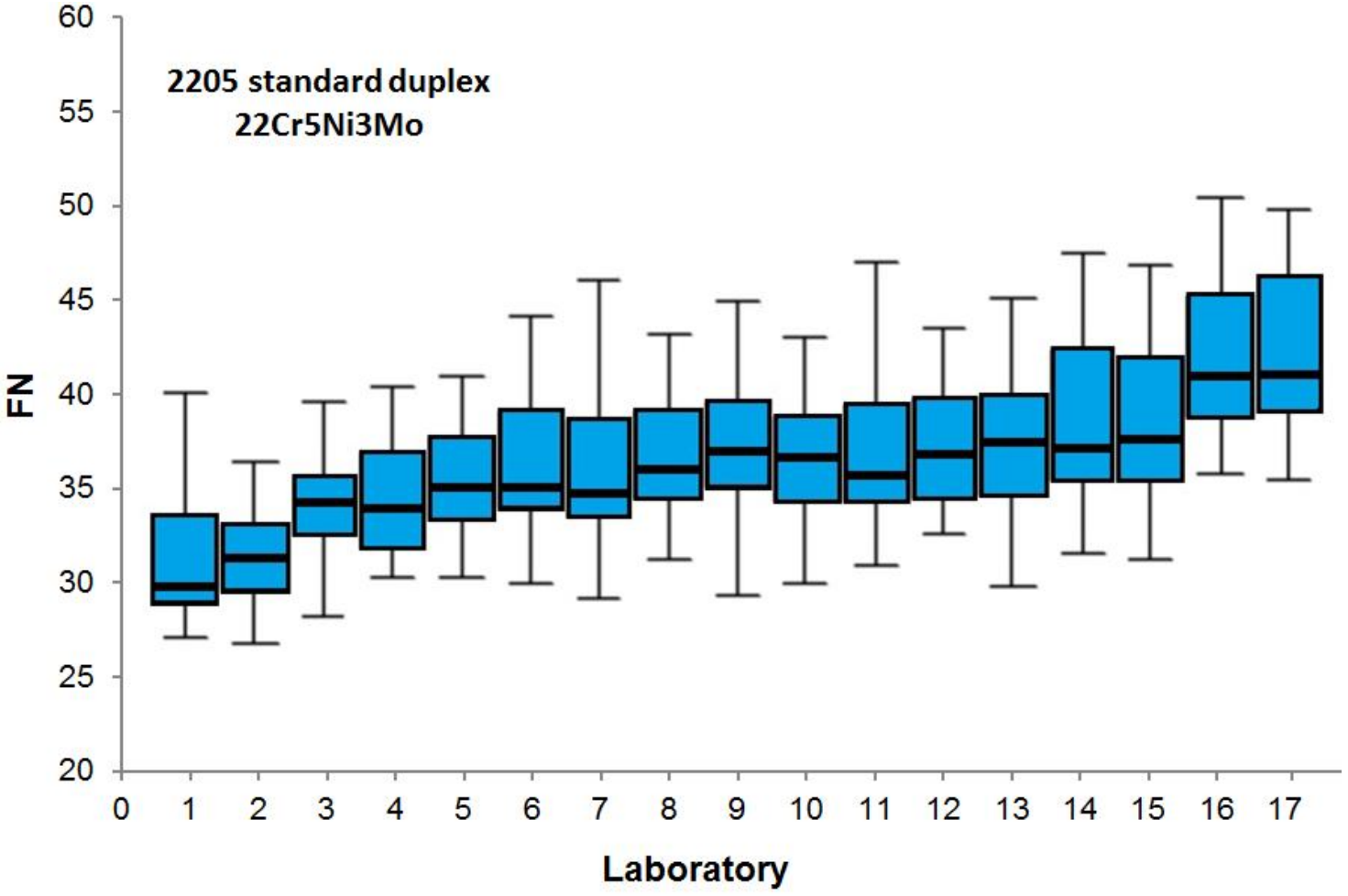
Heat input

Degree of fusion (dilution)



Ferrite measurement varies between labs

IIW round robin test 17 labs



Failure when welding with FCAW 2507/P100-PW

Crack in feeding screw in 12 mm standard duplex 2205

Welding in horisontal position

Welder unsatisfied with visual appearance – GTAW treatment without filler metal

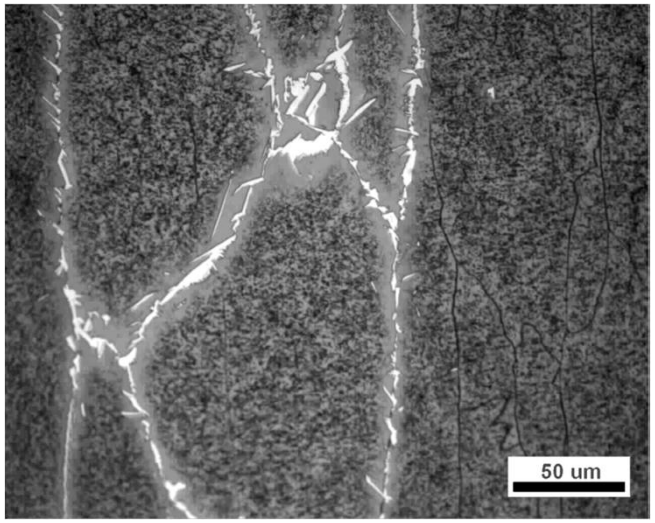
Ferrite content locally 80–90% – brittle weld and cracked after short time in service

On whole feeding screw...

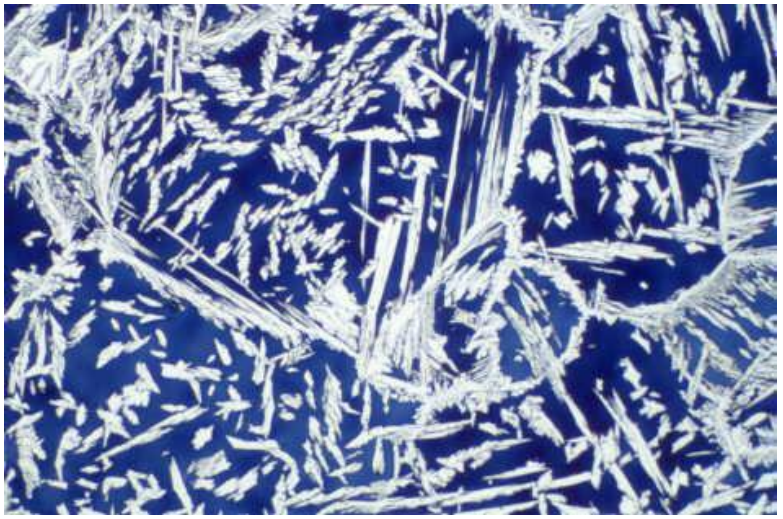
GTAW treatment without filler completely forbidden on duplex constructions

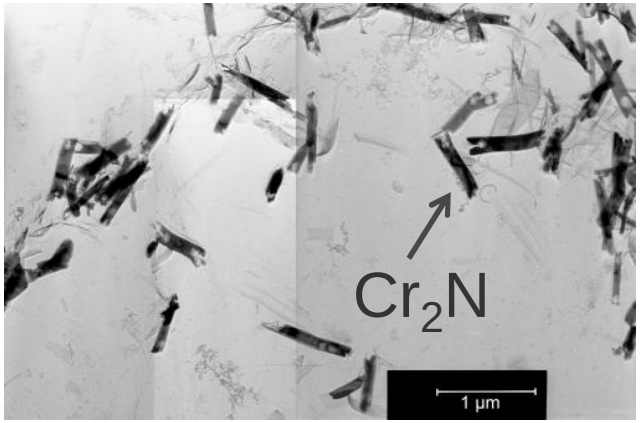
Duplex microstructure after welding

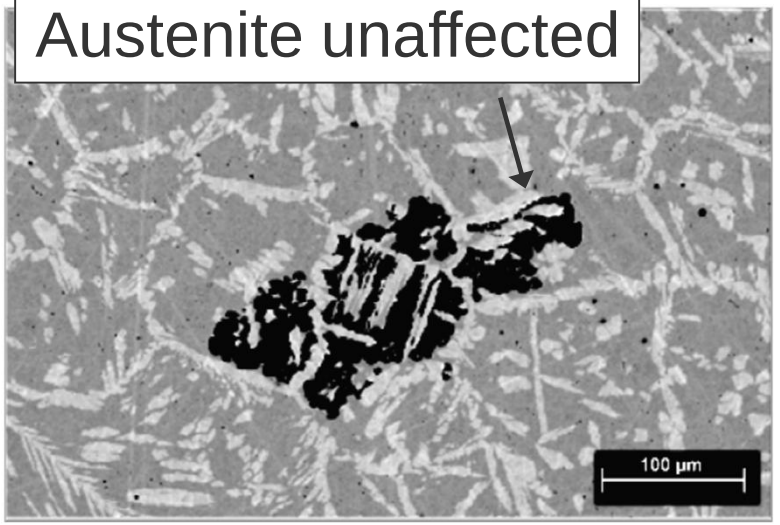
Depends on composition, cooling rate, etc.



High ferrite without filler

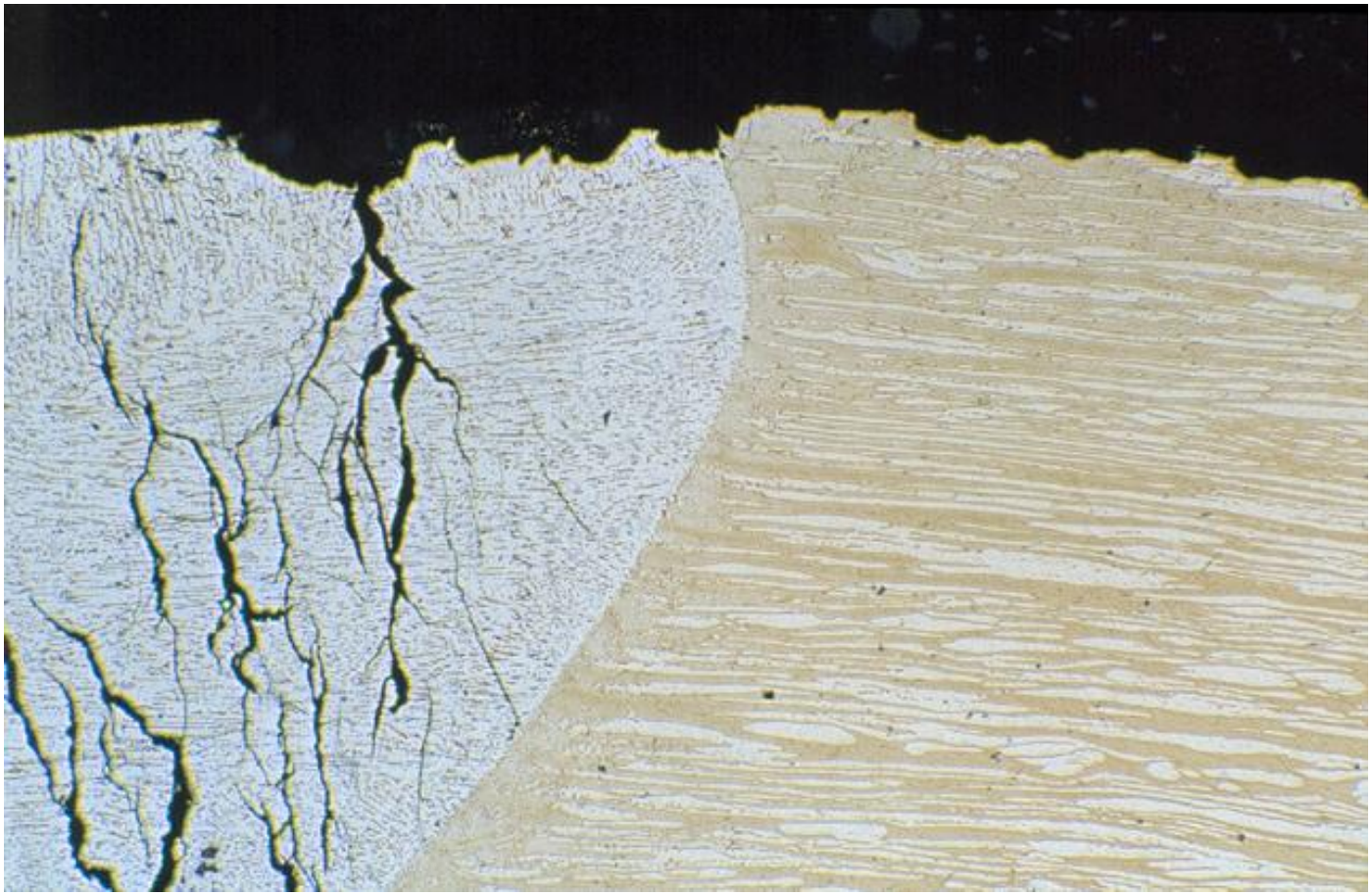






Use of austenitic fillers on standard duplex

SCC in 1% NaCl 200°C, 200h with 19Cr19Ni2.5Mo filler



Austenitic weld metal with 10% ferrite - result in SCC in UNS S32205 joints

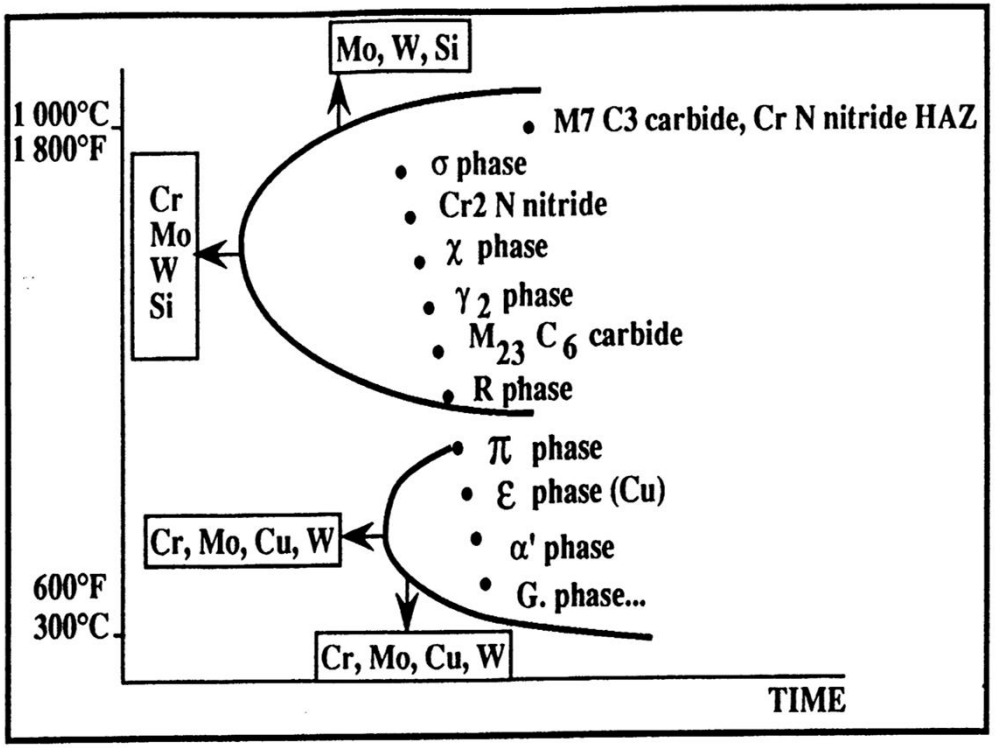
Precipitation of intermetallics (sigma, chi)

Slow cooling rate > 2 kJ/mm

Decreased corrosion resistance and toughness

Alloy and time dependent

Too much energy and time
at sensitive temperature



Source: Outokumpu

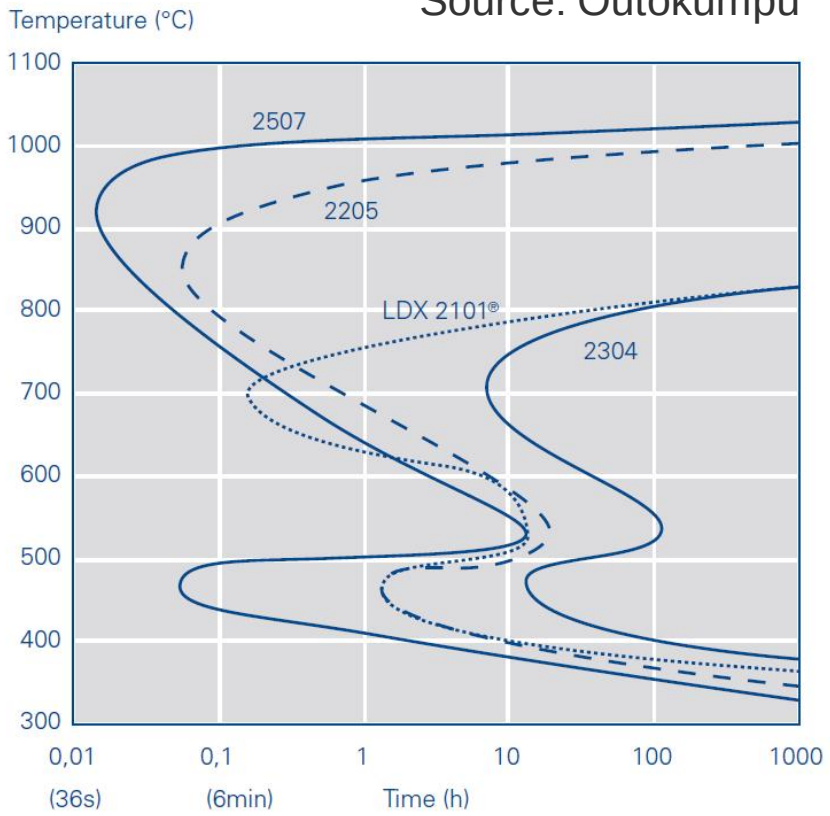


Fig. 1. Curves for reduction of impact toughness to 50% compared to solution annealed condition.

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Precipitation of intermetallics (sigma, chi)

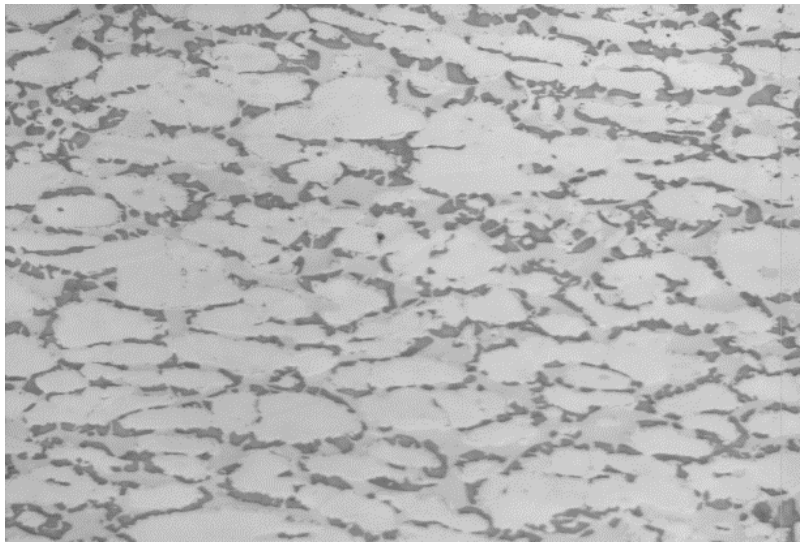
Slow cooling rate > 2 kJ/mm

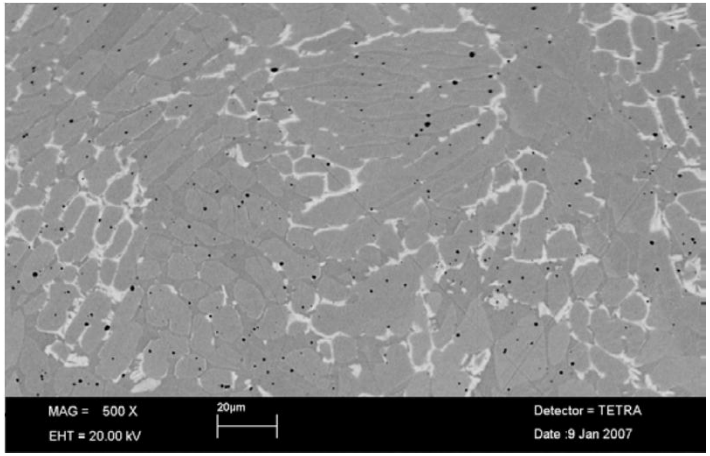
Specified max heat input
superduplex ≤ 1.5 kJ/mm

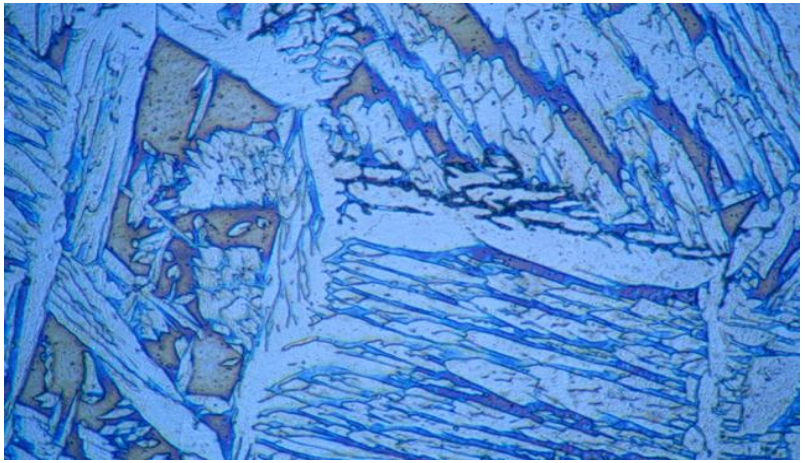
Multipass welding

Interpass (multipass)
temperature 100-150°C

Avoid high heat input in “cold pass”
ito avoid sigma in root bead







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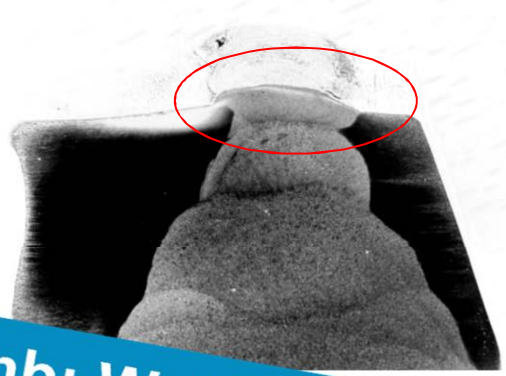
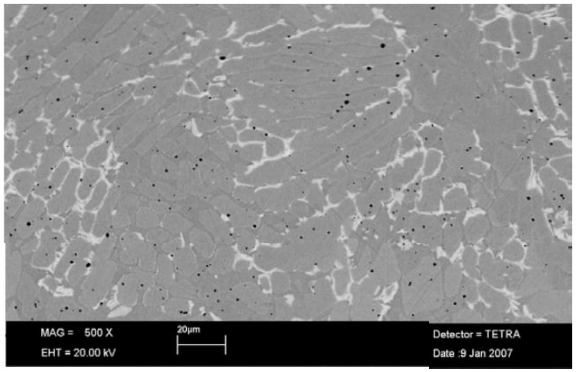
Corrosion attack in 25 mm 2507 superduplex

H-LO45 position with incorrect welding procedure

Pipe system for desalination – TIG (root) and SMAW(rest)



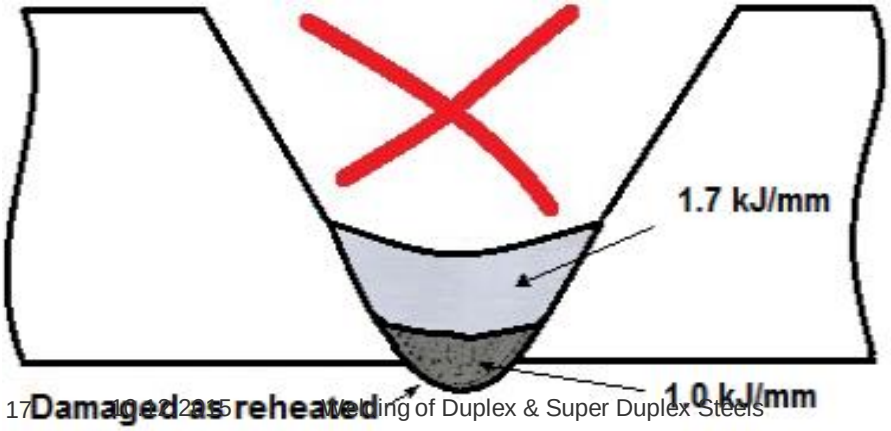


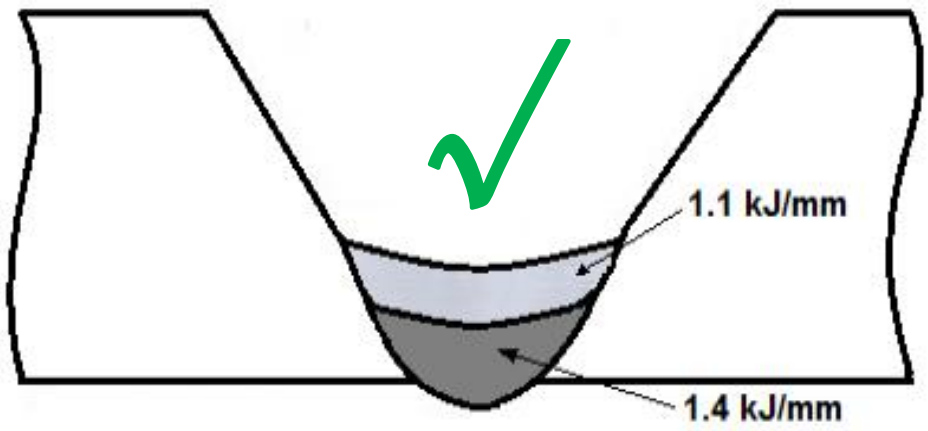
Rule of thumb: Weld cold pass with 70-80% of heat input used for root pass

Root welde… …J/mm)

Subsequent welds welded with hig…

Precipitation of intermetallic phases and decreased corrosi…

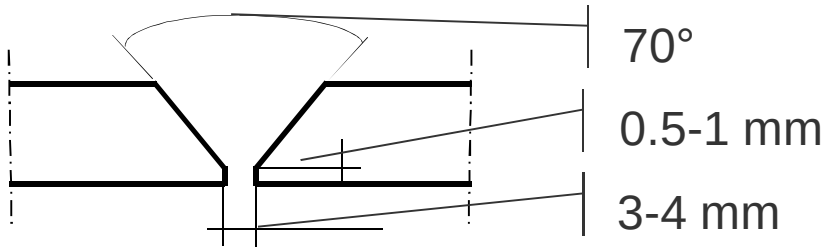


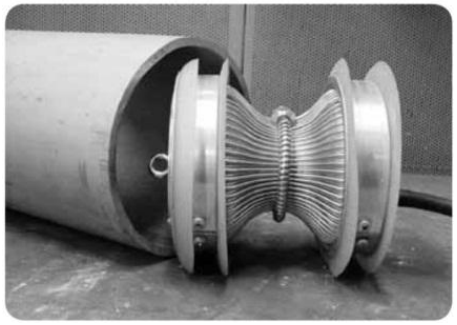


GTAW – most beautiful method

Highest mechanical properties and corrosion resistance

- High quality welds
- Low productivity
- Root and cold passes





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Domestic water heaters welded with GTAW

Design example EN 13445 at 10 bar, Ø 500 mm and 100˚C

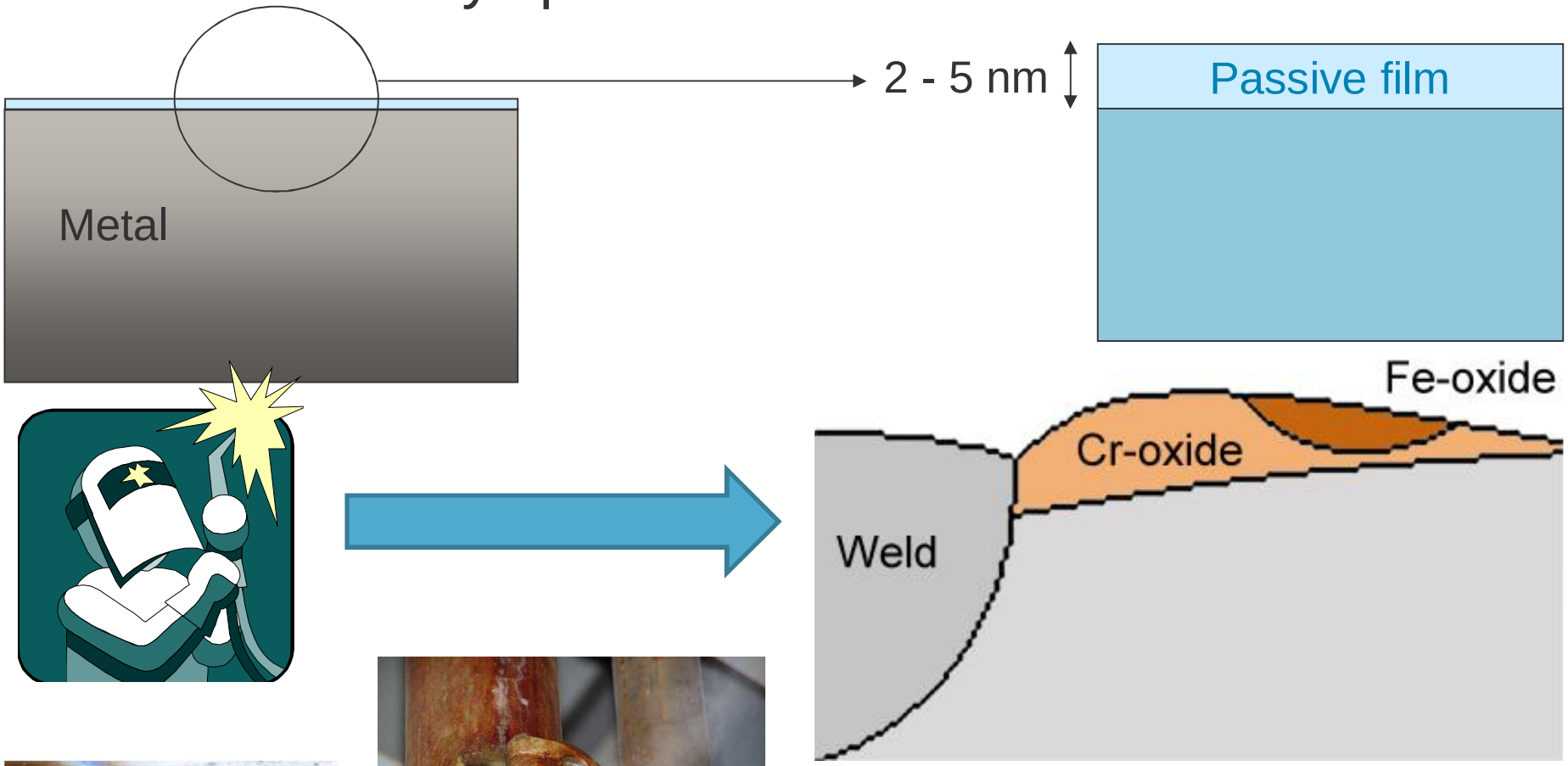
Austenitic 316L	1.8 mm + risk of SCC
Lean duplex LDX 2101	1.0 mm
Lean duplex 2304	1.15 mm
Duplex 2205	1.04 mm
Ferritic 444	1.52 mm

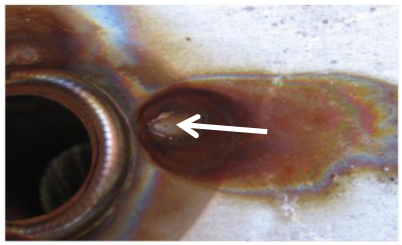
Thin material welded with GTAW

Matching over-alloyed filler metal

Courtesy of Kingspan
Hot Water Systems Ltd

Weld oxide destroys passive film





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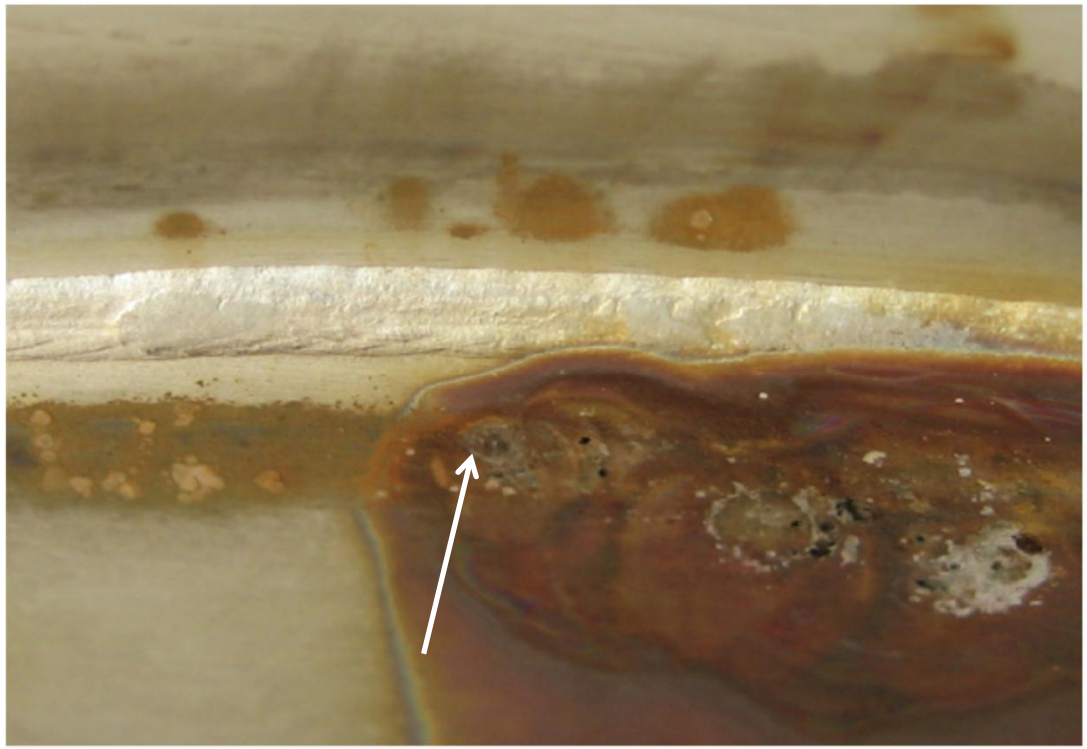
Use backing gas – minimize oxygen content

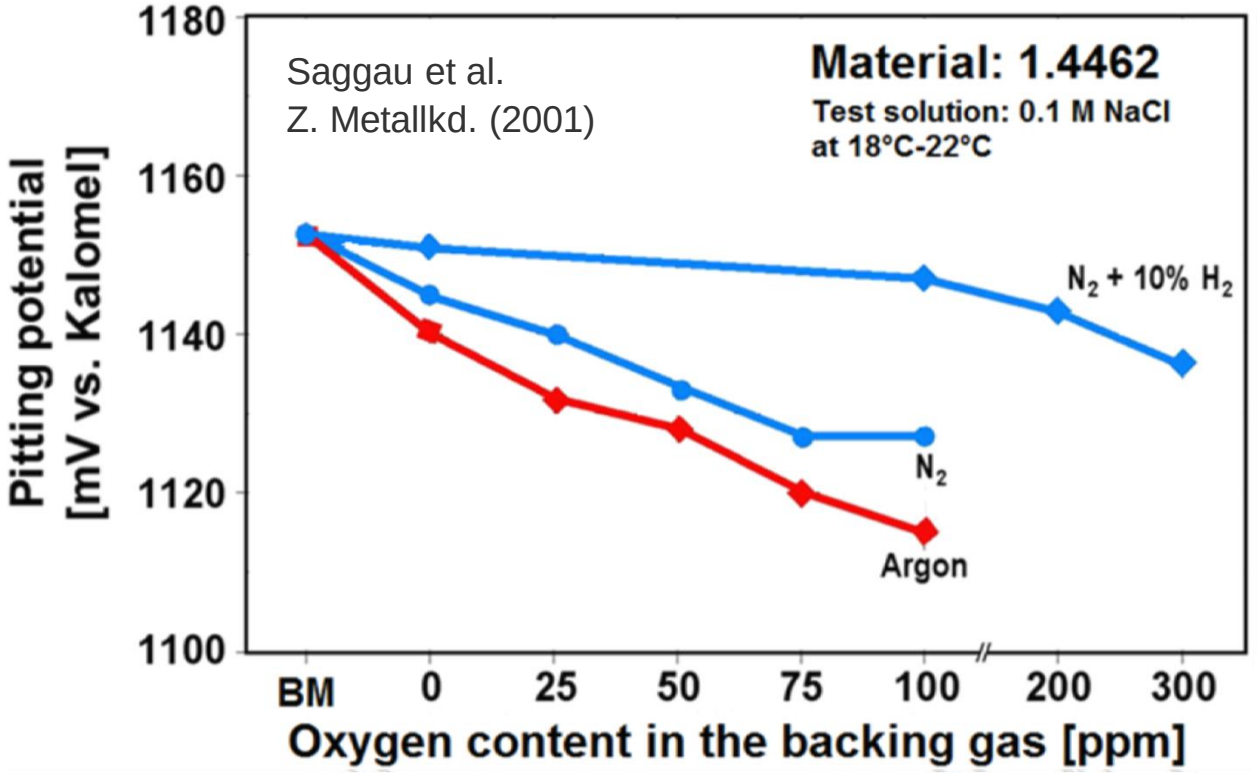
Application with adapters, cardboard or tape



Corrosion in Fe-rich oxide

Effect of oxygen content in backing gas

Straw yellow colour normally acceptable ~ 50-60 ppm oxygen



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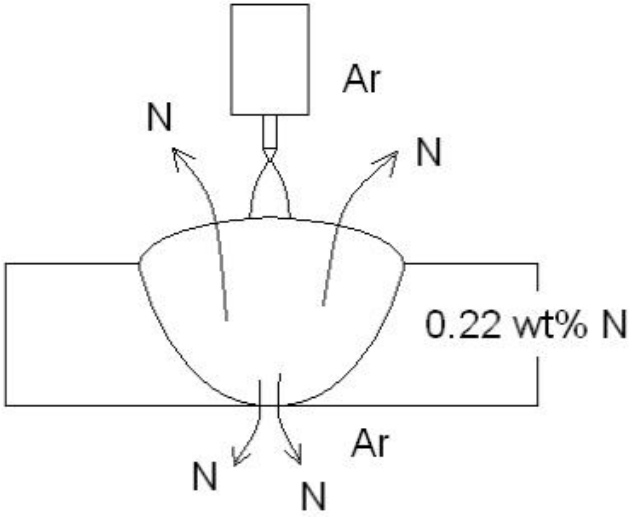
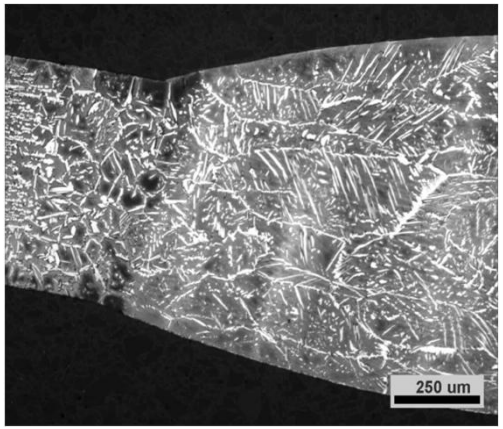
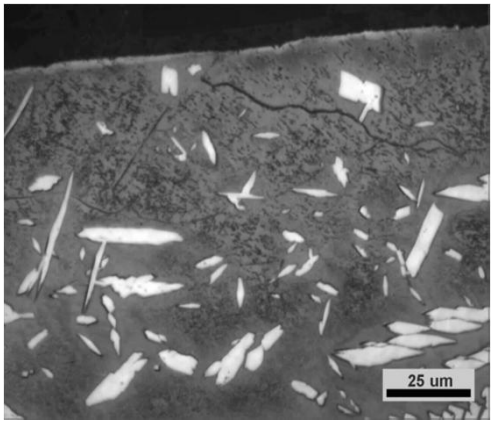
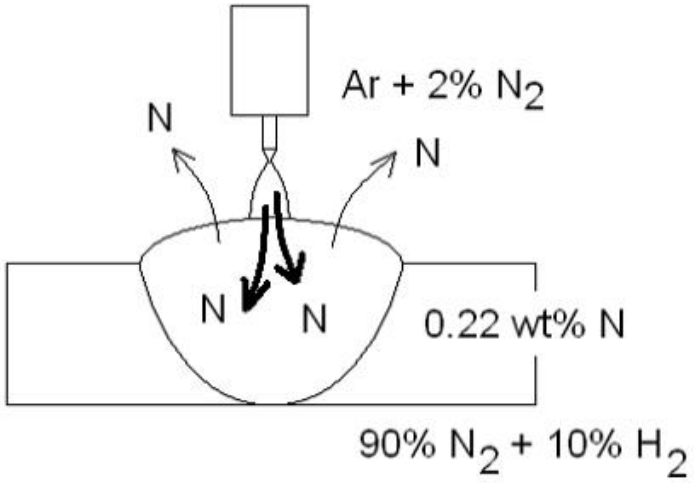
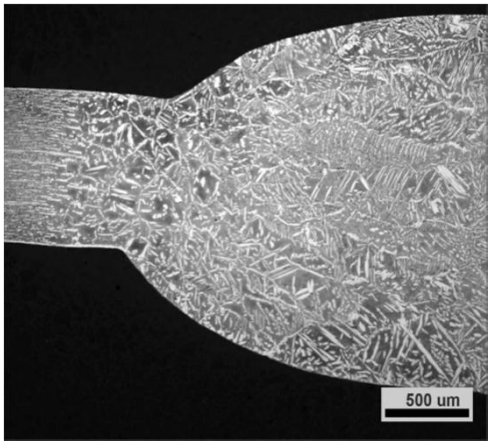
Effect of shielding and backing gas (GTAW / TIG)

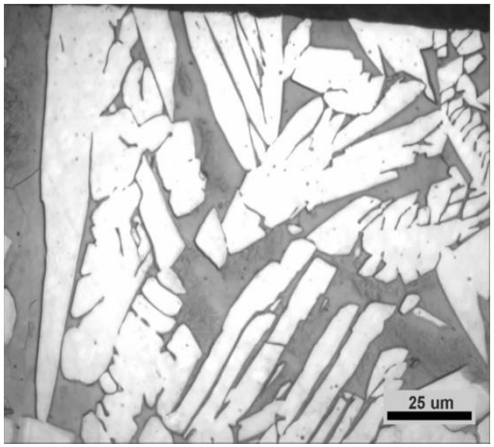












Westin (Welding in the World 2010)

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Lean duplex stainless steel

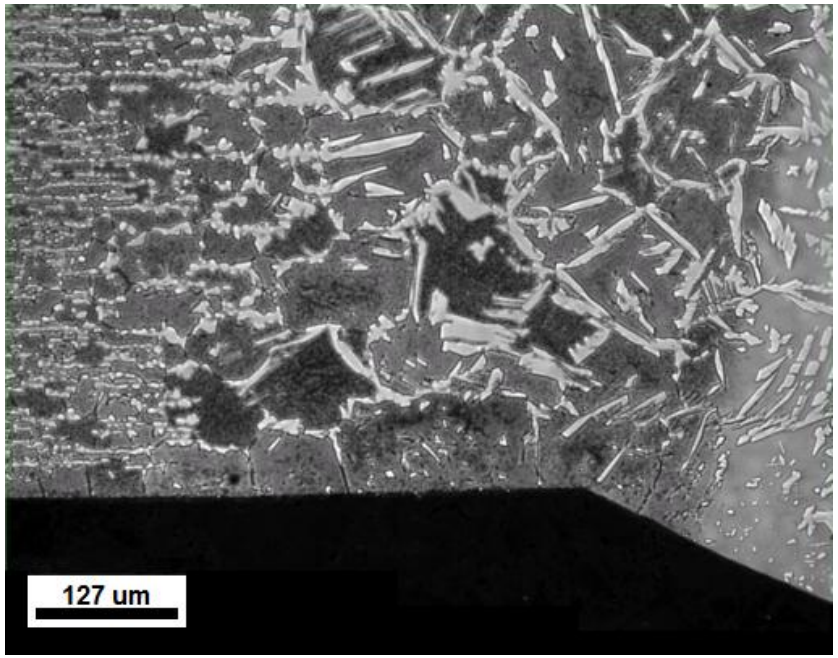
Welded without gap with GTAW method

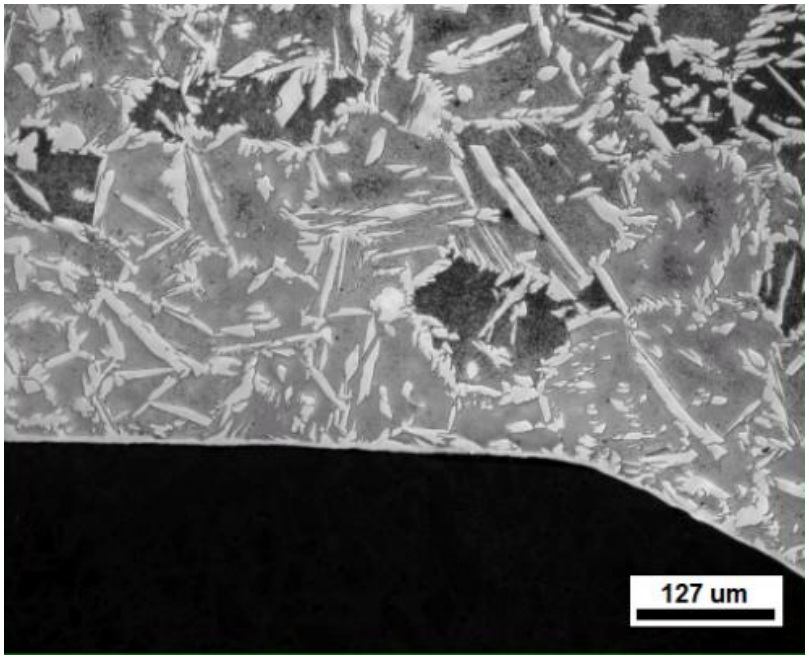
Pure argon as backing gas

- Nitrogen loss
- High surface ferrite content

90% N_2 + 10% H_2 (N_2 + 0-10% H_2)

- Uniform phase balance
- Protective surface layer of austenite





Westin & Serrander (Welding in the World 2012)

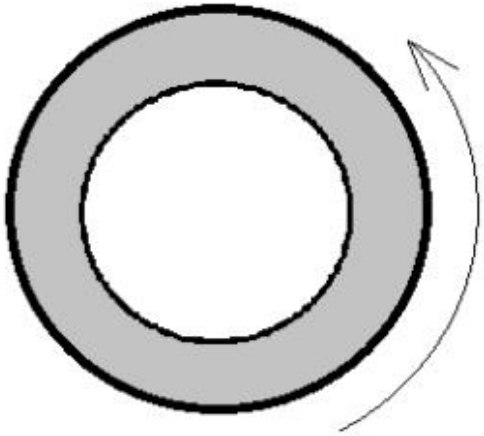
Customer testing – WPS GTAW + FCAW

15 years successful welding of standard duplex

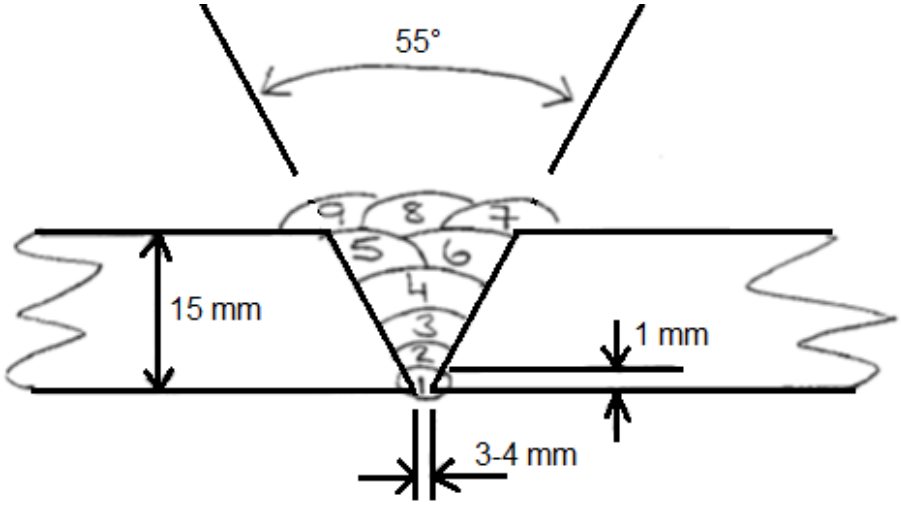
Ø268.6 × 14.27 mm pipe of superduplex UNS S32760
Zeron 100 GTAW + Avesta 2507/P100-PW NOR FCAW

5G, V joint, interpass temperature max. 100°C

Tensile, bend, hardness, stress corrosion, impact toughness test and ferrite content OK



Pass	Method	HI, kJ/mm
1	TIG	1.0
2	TIG	0.6
3	TIG	0.9
4	FCW	1.1
5-9	FCW	0.9-1.5



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Customer testing – WPS GTAW + FCAW

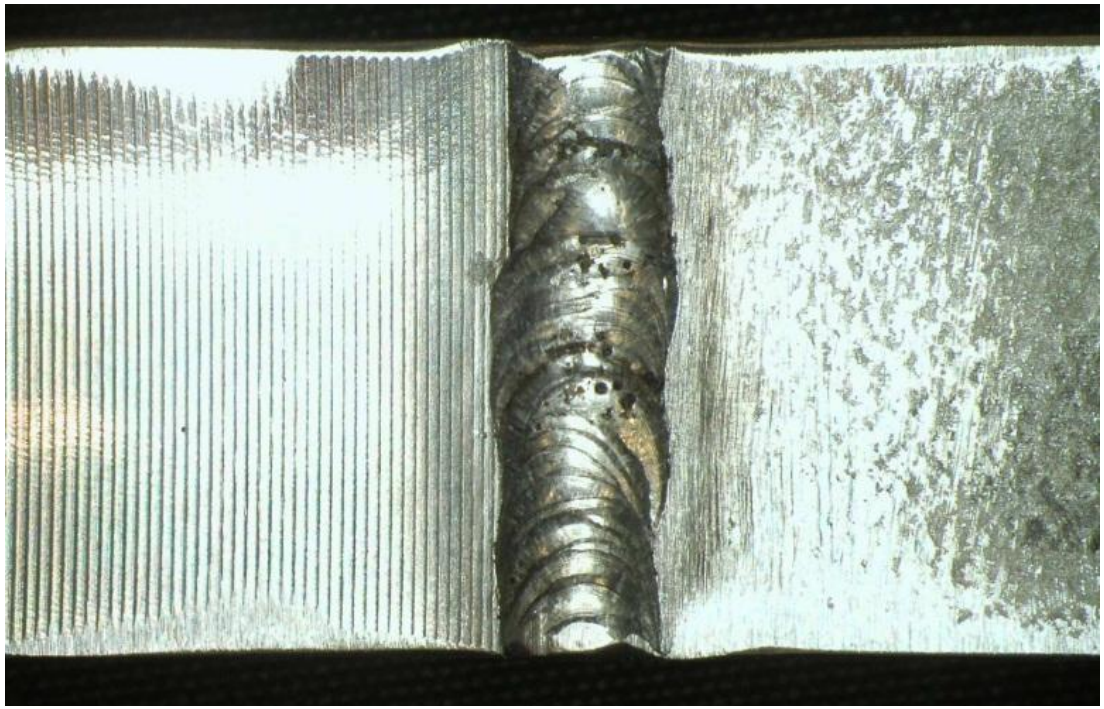
Failed ASTM G48 corrosion test

Pitting attack in GTAW root (not FCAW passes)

Solution to change backing gas from pure argon

Pure nitrogen – no pitting and 3 - 4.01 g/m^2

95% N_2 + 5% H_2 (no pitting and 1 - 2 g/m^2)



New testing successful Tensile, hardness, bend, stress corrosion, corrosion, impact toughness and ferrite content OK

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Corrosion testing of 7 mm 1.4410 / S32750

H-LO45 GTAW (root) + GTAW (pipe)

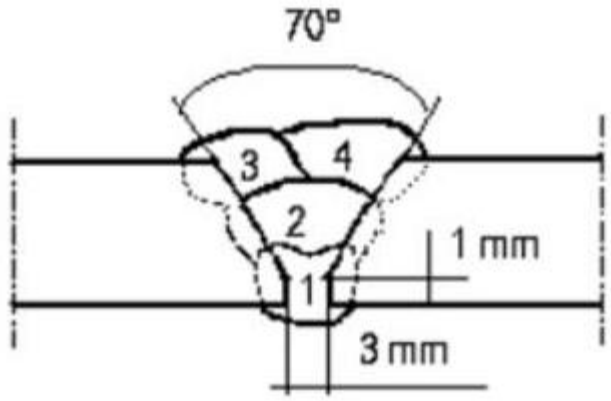
ASTM G48 E – Pickling: 2 h, 40°C, 20% HNO_3 + 5% HF

GTAW – shielding gas Ar + 2% N_2, 2.4 mm Avesta 2507/P100

FCAW – Ar + 18% CO_2 + 0.03% NO, 1.2 mm Avesta 2507/P100-PW

Backing gas 90% N_2 + 10% H_2, interpass temperature < 100°C

Run	Polarity	Current, A	Voltage, V	Speed cm/min	Energy, kJ/mm
1	DC-	87	11.0	2.8-3.8	0.9-1.2
2	DC+	153	24.0	21.5	0.81
3	DC+	156	24.0	28.0	0.64
4	DC+	161	24.3	30.0	0.62



No pitting attack and weight loss << 4 g/m² (0.0000 and 0.5535 g/m²)

Comparison of different backing gases

GTAW 2507 + FCAW Avesta FCW 2507/P100-PW NOR

4 mm root gap, shielding gas 100% Ar / Ar + 18% CO_2

All side bend and tensile testing approved

Backing gas	Average ferrite content, vol.%		
	BM	WM	HAZ
100% Ar	46 ± 2	54 ± 7	66 ± 5
100% N_2	47 ± 1	44 ± 6	64 ± 3
90% N_2 + 10% H_2	47 ± 2	44 ± 9	67 ± 4

Backing gas	Average impact toughness, J	
	20°C	-46°C
100% Ar	67	51
100% N_2	63	44
90% N_2 + 10% H_2	59	43

Backing gas	40°C after pickling	
	Weight loss	Pitting
Ar	5.76	Edge attack
	8.11	Edge attack
N_2	4.15	
	8.16	
N_2/10H_2	1.05	Edge attack
	2.86	Edge attack

Slag shielded arc welding methods

Covered electrodes – MMA / SMAW

Flexibility – all positions

- Chemical composition

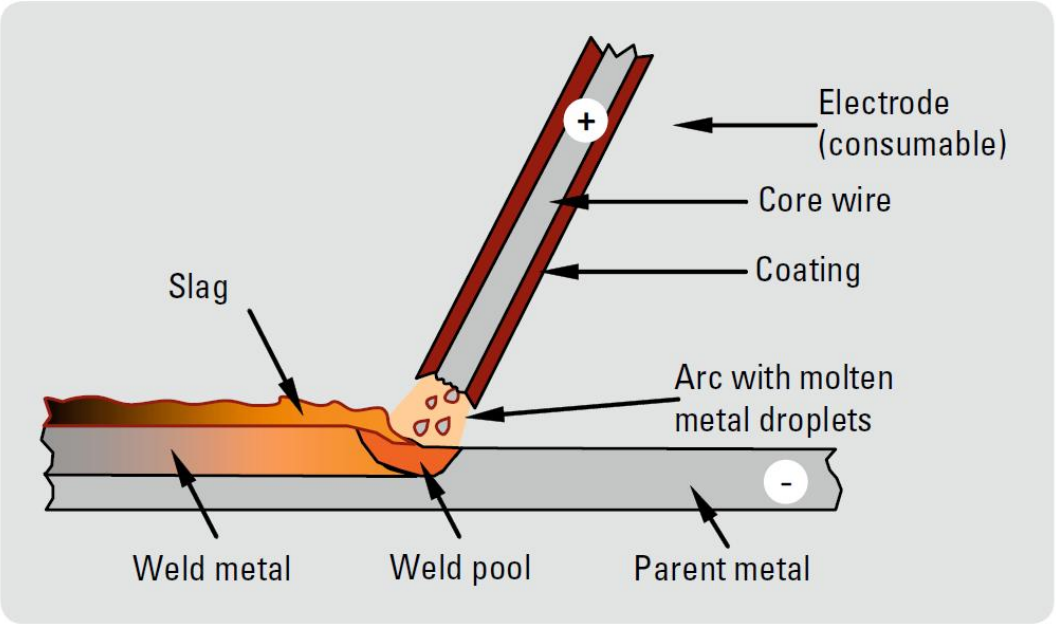
Good weldability

Horizontal and vertical-up position

Material thickness ≥ 2 mm

Suitable for:

- Fabrication welding
- On site welding
- Repair welding



Requires post weld cleaning of root (weld oxide) in drinking water applications!

HP gas cooler for Premier Oil (Indonesia)

6 mm superduplex material S32750

GTAW + SMAW Avesta 2507/P100

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P-51, P-52 & P-54 Oil Platforms

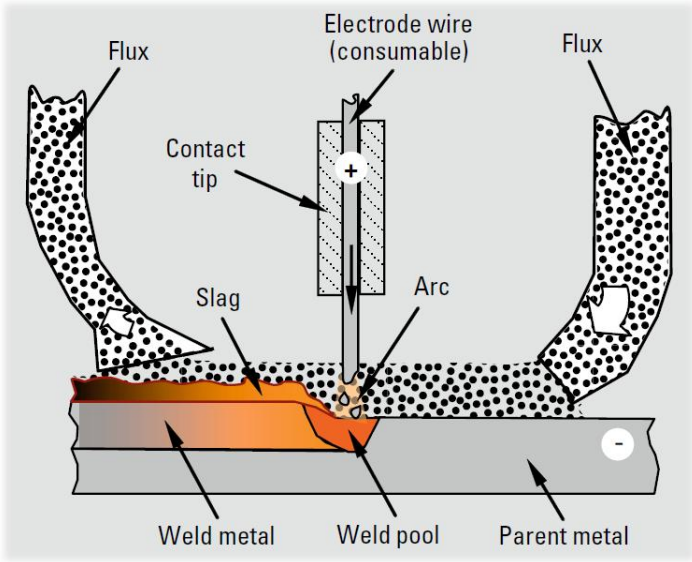
Heat exchangers for crude oil for easier pipe transportation, Weight 53 tons. 6.3–50.8 mm superduplex UNS S32750

Filler Metals:	Dimension
Thermanit 25/09 CuT (SMAW)	3.25 + 4.0 mm
Thermanit 25/09 CuT (SAW)	2.40 mm
Marathon 431 (Flux)	Flux
Thermanit 25/09 CuT (GTAW)	2.40 mm

Engineering: Jaraguá Equipamentos Ltda

Owner: Jurong and Fels Stal Technip

Submerged arc welding SAW – UP



Good weldability – high productivity

Welding thicker materials ≥ 10 mm

Suitable for prefabrication

Penetration less than in standard austenitics

Important with right wire and flux combination

First run(s) can be made with another method

Use basic flux for highest possible impact toughness

Heat input limited in LDX 2101 and 2507

- Avoid big weld pools and high dilution of parent metal
- 2205 & 2304 Heat input up to 3 kJ/mm
- LDX 2101 & 2507/P100 Heat input max 1.0 kJ/mm

Pressure vessel – oil treater & degasser

Fillet welds with Ø1.2 mm Avesta FCW 2507/P100-PW NOR

TIG + SAW for vessel

FCAW for fillet welds

Superduplex base material

NORSOK requirements

40 J impact toughness at -46°C

Alvheim Project

Separator tanks for petrochemical application

Customer: SB Verksted, Drammen, Norway

22% Duplex steel, wall thickness 28 mm

Filler metal: Böhler CN 22/9 PW-FD,
Thermanit 22/9 UP +
Flux Marathon 431
(total weight 3 500 kg)

Engineering: Aker Kvaerner Engineering

Owner: Marathon Petroleum/Conoco Phillips

Courtesy of SB Verksted

Welding procedures

Avesta Welding

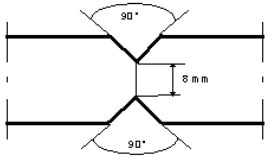
WPAR			WPAR No SAW-1
Welded acc. to pWPS:	1		Side:
Issued by:	M. Larén		Date: 98-07-30

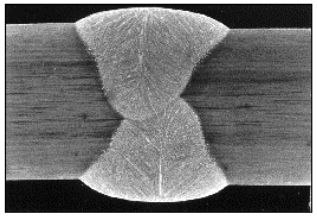
		Charge:	Thickness:	Group:	Pipe Ø:
Base-material:	A: 2205		16,5 mm		
	B: 2205		16,5 mm		

Preheat: °C
Interpass temp.: <150°C
PWHT: °C h

Backing:
No grinding of backside.

Welding position: 1G (PA)





Thickness: 16.5 mm Root face: 8 mm
Joint angel: 80°

Notes:
Drag angle 15° towards travel direction (backhand).

Run	Process	Filler material	Dia.	Batch No	Gas/Flux
1-2	SAW	2205	3.20 mm	0322	AVESTA 805
					Lot 2779

Run	Polarity	Current Ampere	Voltage Volt	Speed cm/min	Energy kJ/mm	Stick out	Wire feed m/min	Note
1	DC+	635	32,5	50	2,48	20 mm		
2	DC+	635	32,5	50	2,48	20 mm		

Chemical analysis (Pure weld metal)

C	Si	Mn	P	S	Cr	Ni	Mo	N and Cu
0,016	0,51	1,44	0,016	0,001	22,7	8,65	3,05	0,17/0,10

Tensile test Rp0.2	Rm	As (%)	Impact test Notch	Temp	Joule	Average	Bend test Mandrell dia. 3xT
507 Mpa	716 Mpa	29	KV	+20 °C	198,184,173	185	Root, Cap, Side: OK
495 Mpa	694 Mpa	30	KV	-40 °C	63, 58, 68	63	

Corrosion test Type	Temp	Result Weight loss	Preparation (Pickling, brusching, As welded)
ASTM G48-A	27.5°C	No attacks.	Pickling+brushing
	30°C	Attack in weld: 0.0012 g.	

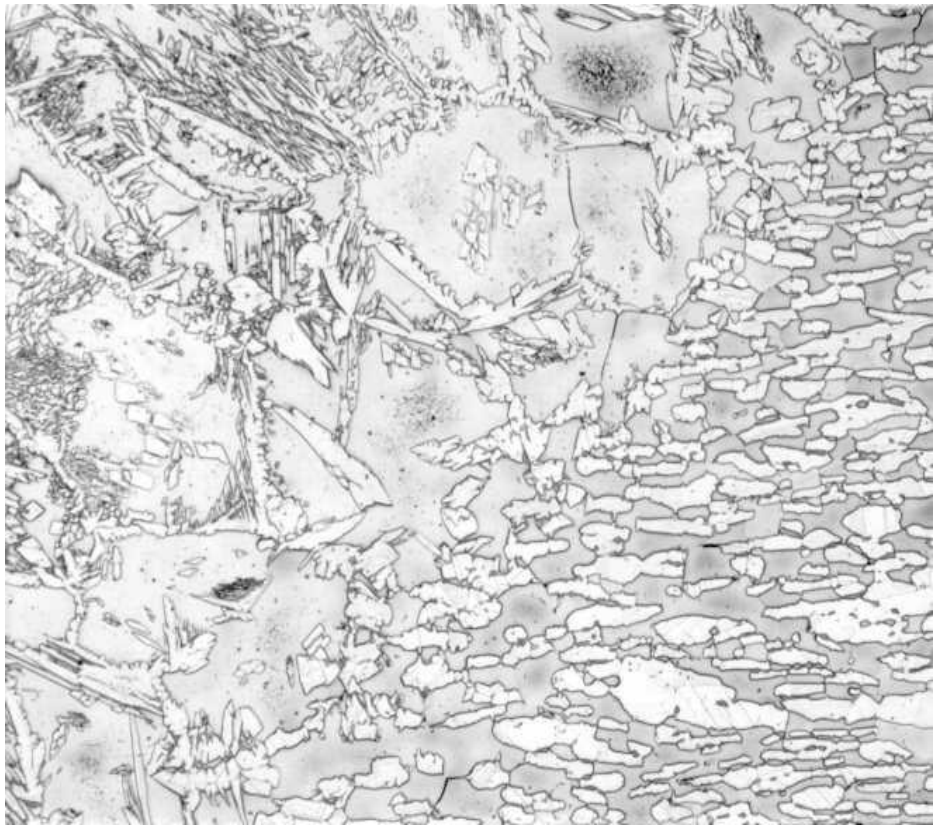
X-ray: Grade 5 Aa — Note: Some small porosity

Liquid penetrant: None — Note:

Micrographic examination

		ASTM E562	Ferite scope MP-3
Ferrite content: (weld metal)	1.	54.7%	51.4%
	2.	54.0%	50.6%

Note: See report No.: LR 222/98



Establish proper welding procedure and follow it!

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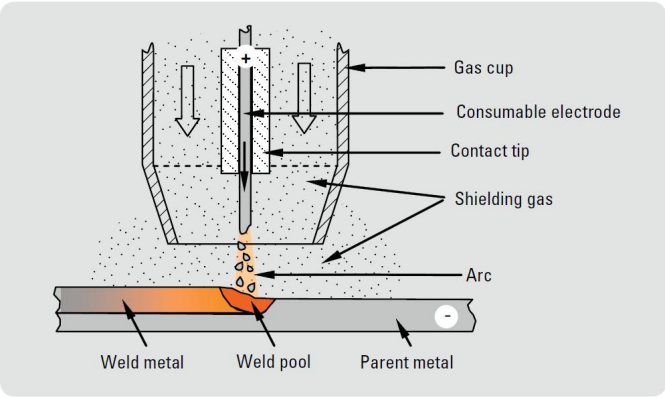
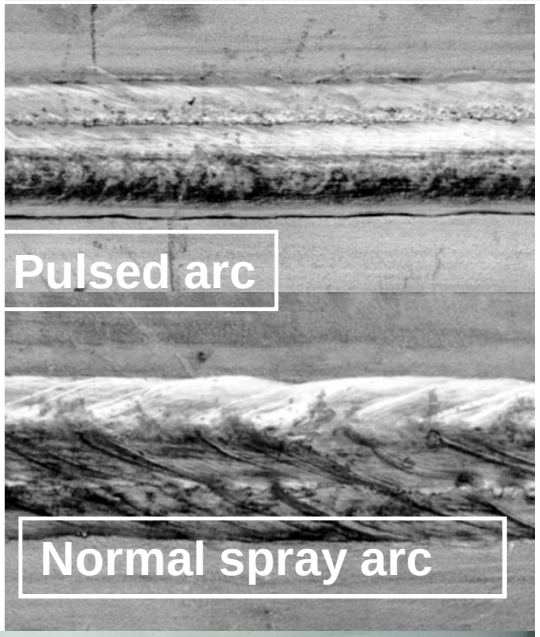
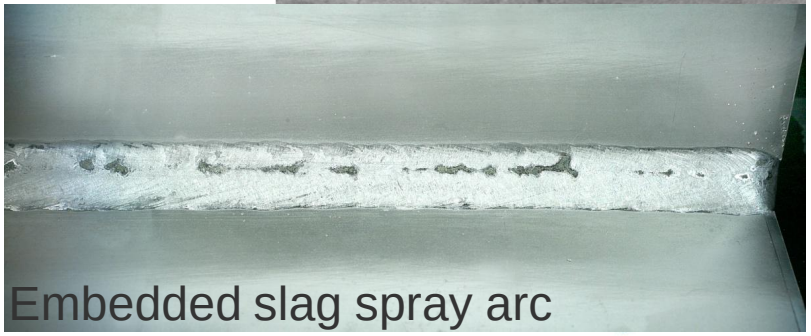
Gas shielded arc welding – MIG / MAG – GMAW



- Fluidity and arc stability lower than standard austenitic fillers (spatter)
- Best results with synergic pulsing
- Recommended shielding gas
  - Ar + 30% He + 1-3% CO_2
  - Ar + 2% O_2 or Ar + 2-3% CO_2
- High BM nitrogen content increases sensitivity to porosity – superduplex pure argon
- FCAW an alternative (less pores)

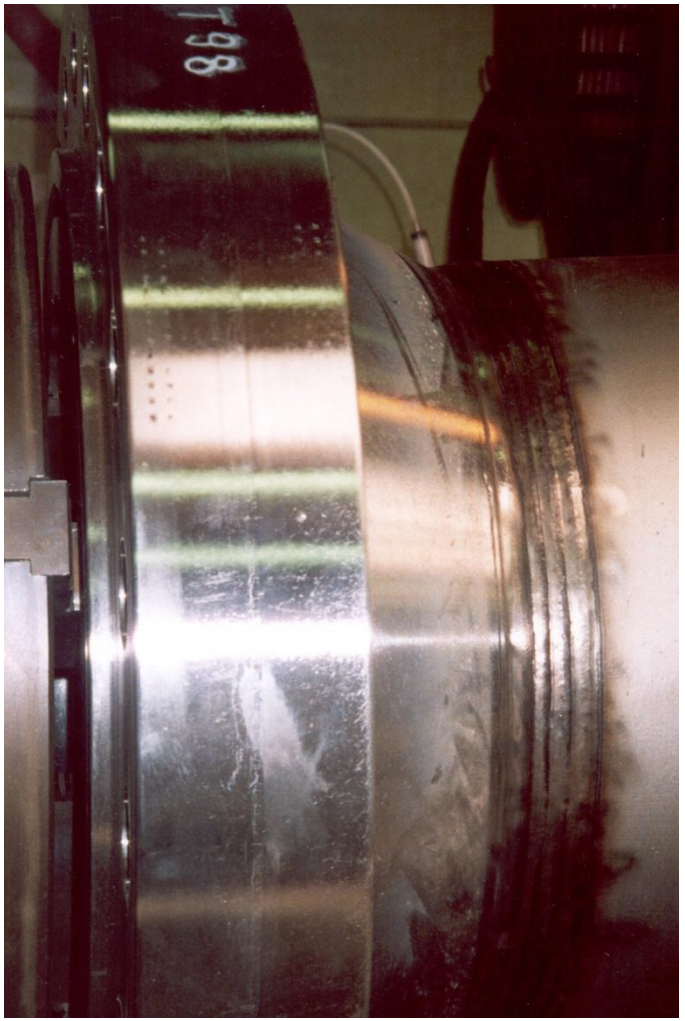



Spatter and embedded slag short arc


Embedded slag spray arc

Avesta 2205 + Avesta FCW-2D 2205

Pipeline oil&gas NAM



Slag shielded arc welding

Flux cored arc welding FCAW, t > 5 mm

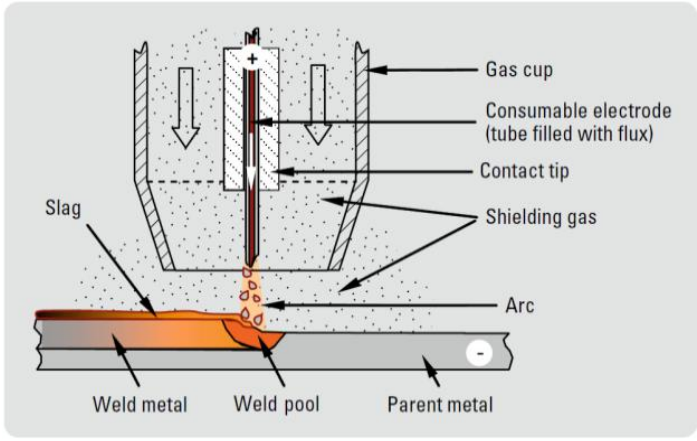
DC+ with normal GMAW machines (4 feeding rolls)

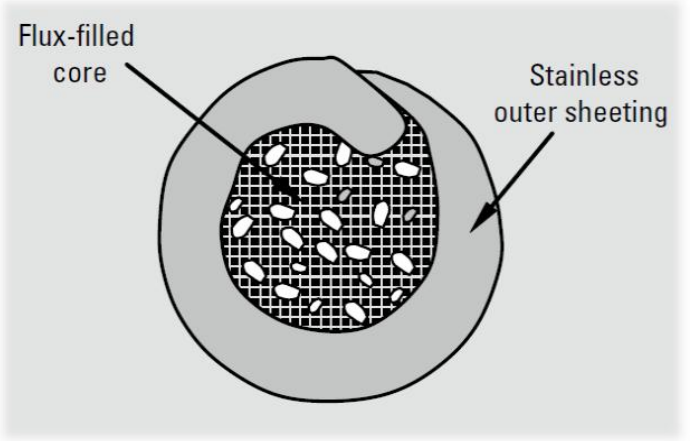
Suitable for prefabrication and onsite welding

Single side welding against ceramic backing

Horizontal and vertical wall position wires

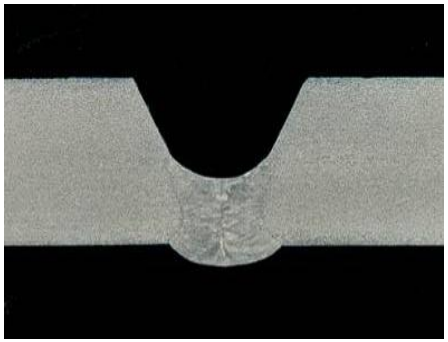
Good positional weldability





-PW

Slag shielded methods give lower impact toughness



Welding with duplex flux-cored wire

Compared to solid wire GMAW – MIG / MAG

Increased productivity and decreased total welding costs

Good side-wall fusion

Wide arc provides uniform, deep penetration

Reduces risk of weld defects (lack-of-fusion)

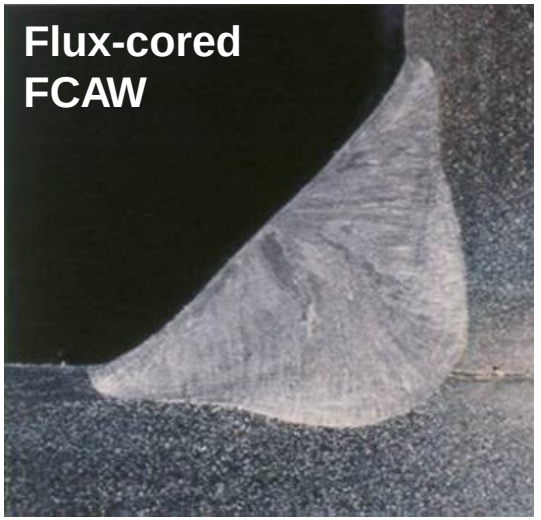
Less risk of spatter and porosity

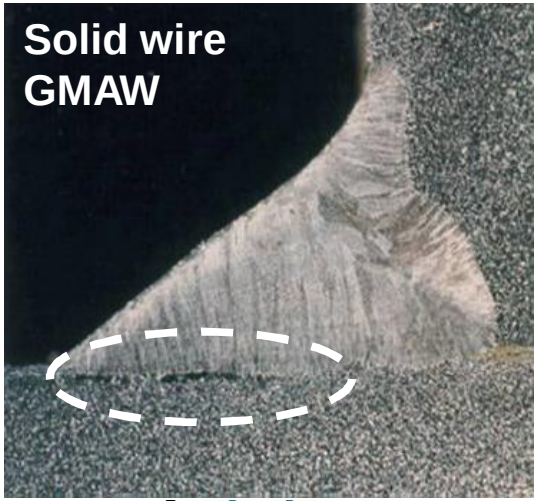
Shielding gas – Ar + 18-25% CO_2
Low shielding gas costs

Good slag removal with suitable welding parameters

Slag-shielded methods give lower impact toughness

Slag removal needed





Change method for improved productivity

Comparison of weld length for fillet welds

Throat thickness 3 mm, welding time 1 min

Flux-cored wire
Ø 1.2 mm

Solid wire
Ø 1.0 mm

Covered electrode
Ø 3.2 mm

FCAW GMAW / MAG SMAW / MMA

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ONE STEP AHEAD.

References

Avesta FCW 2507/P100-PW
Avesta FCW 2507/P100-PW NOR

Companies in France, Germany, Finland, Holland, Poland, UK, Denmark & Spain

Welding duplex and superduplex stainless steel

Repair welding in foundries (filling pores after casting)

Shaft seal and bearing systems for marine industries

Cladding of separators for water sludge, pulp and paper, milk, etc.

Offshore tubes

Water pumps

Pressure vessel – oil treatment & degassing

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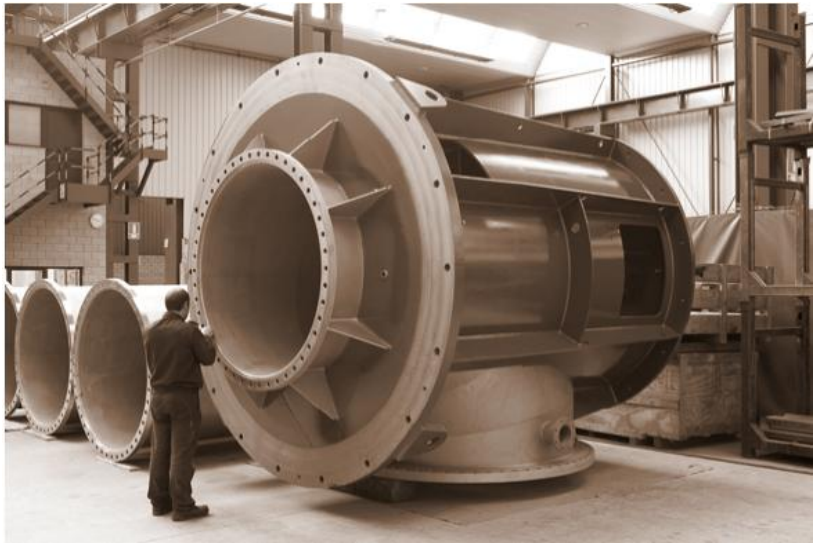
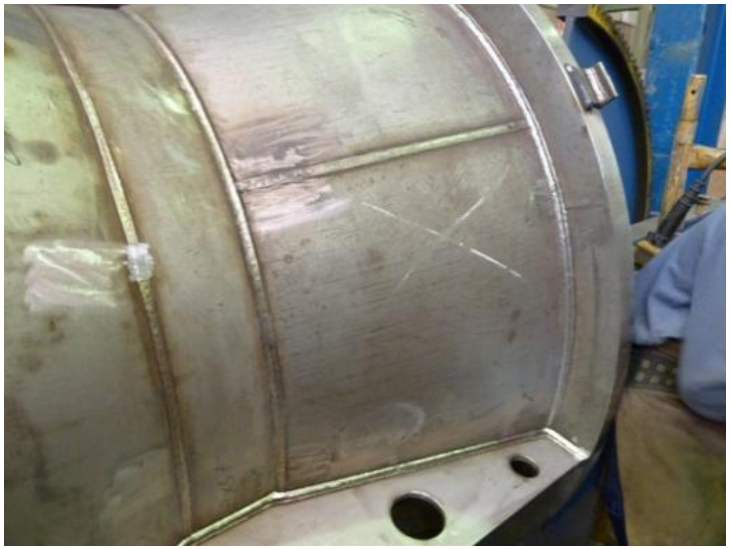
Seawater pumps, Spain

Avesta FCW 2507/P100-PW

Duplex and superduplex stainless steel

Avesta FCW 2507/P100-PW for improved slag removal





Pressure vessel in Uranus 52N+

Success story – Avesta FCW 2507/P100-PW

French fabricator

Moroccan end customer

Welding of pressure vessel in Uranus 52N+

1100 kg Avesta FCW 2507/P100-PW

Chemical industry segment

Phosphoric acid mixer

No specific technical requirements

Flux-cored wires duplex (pure weld metal)

EN TZ 22 9 3 N L R M/C 3 / 1
AWS E 2209 T0-4 (1) / T1-4 (1)

Designation	C	Mn	Cr	Ni	Mo	N	$Rp_{0.2}$	Rm	A_5	Impact toughness, J	
							MPa	MPa	%	+20°C	Low temp.
FCW-2D 2205 CN 22/9 N-FD	0.03	0.8	22.7	9.0	3.2	0.13	600	800	27	60	40 (-40°C)
FCW 2205-PW CN 22/9 PW-FD	0.03	0.9	22.7	9.0	3.2	0.13	600	800	27	80	55 (-40°C)

Flux-cored wires superduplex (pure weld metal)

EN TZ 25 9 4 N L P M21 2
AWS E 2594 T1-4

Designation	C	Mn	Cr	Ni	Mo	N	$Rp_{0.2}$	Rm	A_5	Impact toughness, J	
							MPa	MPa	%	+20°C	Low temp.
FCW 2507/P100-PW CN 25/9 PW-FD	0.03	0.9	25.3	9.8	3.7	0.23	670	890	26	> 60	34 (-40°C)
FCW 2507/P100-PW NOR	0.03	0.9	25.3	9.8	3.7	0.23	670	890	26	> 60	45 (-50°C)

Pitting corrosion resistance ASTM G48

Pickled samples, test duration 24 h

Corrosion test results CN 22/9 PW-FD Ø1.2 mm
Base material 16 mm EN 1.4462 / UNS S32205, PF (3G), Ar +18% CO_2

Position	Test temperature	Test result (weight loss)
PA	22°C	Pass (0.013 g/m^2)

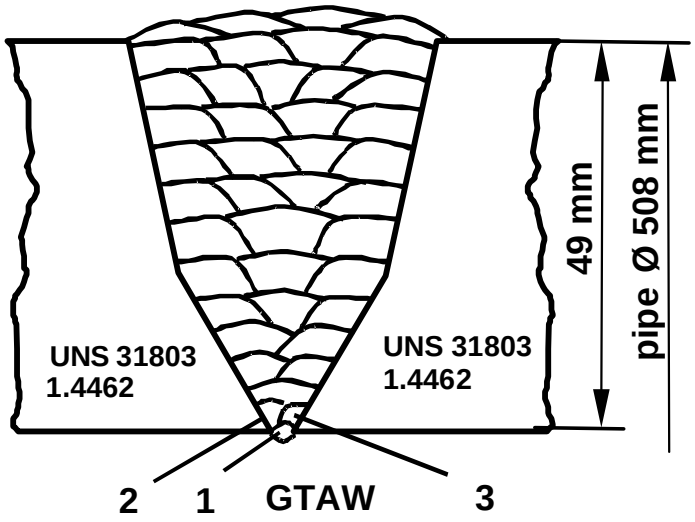
Corrosion test results CN 25/9 PW-FD Ø1.2 mm
Base material 16 mm EN 1.4410 / UNS S32750, Ar +18% CO_2
V-joints welded against ceramic backing

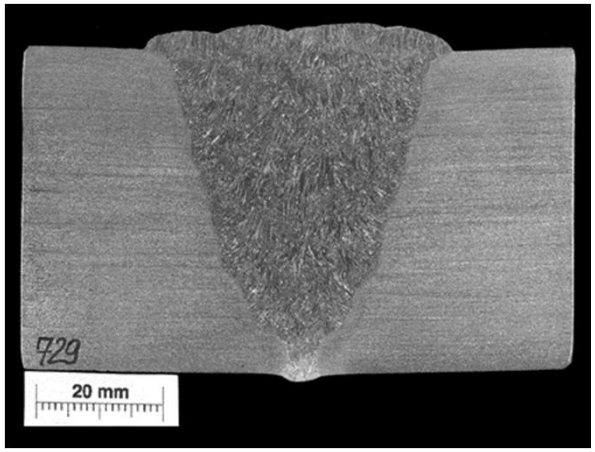
Position	Test temperature	Test result (weight loss)
PA	40°C	Pass (1.45 g/m^2)
PF	40°C	Pass (0.95 g/m^2)

Treshold value pass/fail 4 g/m^2

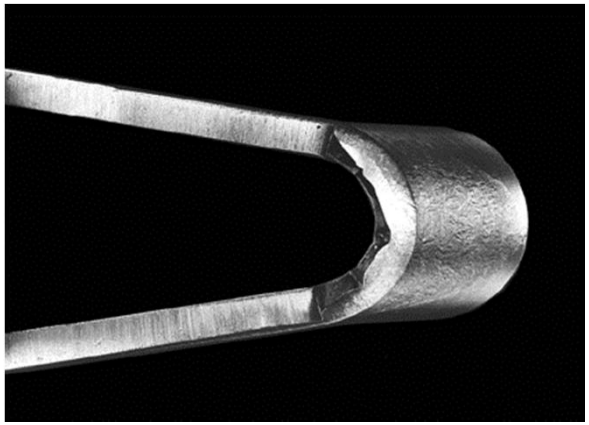
Pipe welded with CN 22/9 PW-FD Ø1.2 mm

Base material 49 mm EN 1.4462, root TIG welded with CN 22/9 N-IG
Welding position: 5G (PF), Shielding gas: Ar + 20% CO_2
Interpass temperature: 180°C, Preheating: ~100°C





EN 910 bend test accepted
50 × 10 mm, 30 mm mandrel, 180° bend angle



EN 875 10 × 10 mm

Location	Temp.	Impact [J]
WM	+20°C	64 61, 65
WM	-46°C	49, 50, 48

Mechanical properties

AVESTA FCW 2507/P100-PW NOR

Base material – 15 mm EN 1.4410, UNS S32750

V-joint, PF position – measured values (free shrinkage)

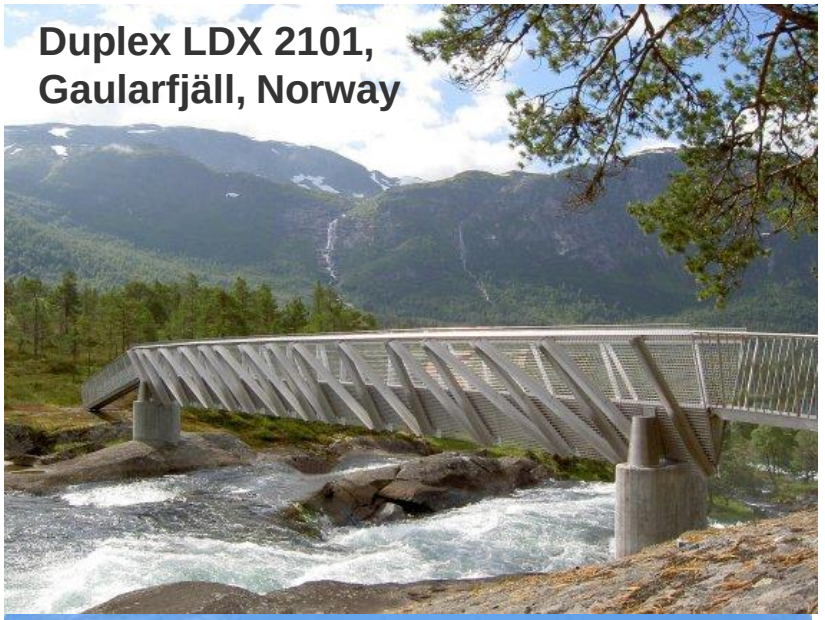
Ar + 18% CO_2 as shielding gas

Tensile test				Impact toughness (ISO-V)		
$Rp_{0.2}$, MPa	Rm, MPa	A_5, %	Fracture	+20°C, J	-20°C, J	-46°C, J
706	844	28	Base metal	52, 56, 63	51, 51, 52	40, 49, 44

Type	Mandrel Ø, mm	Bend angle	Result
Side bend test	4 × t	180°	No cracks

Bridges made of lean duplex

Avesta FCW LDX 2101-PW, 2304-PW applications



Siena, Toscana, Italy
LDX 2101 (1.4162)

voestalpine Böhler Welding

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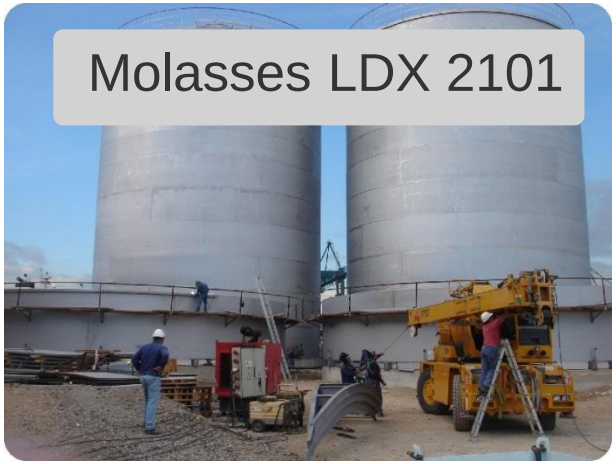
Storage tanks welded with FCW

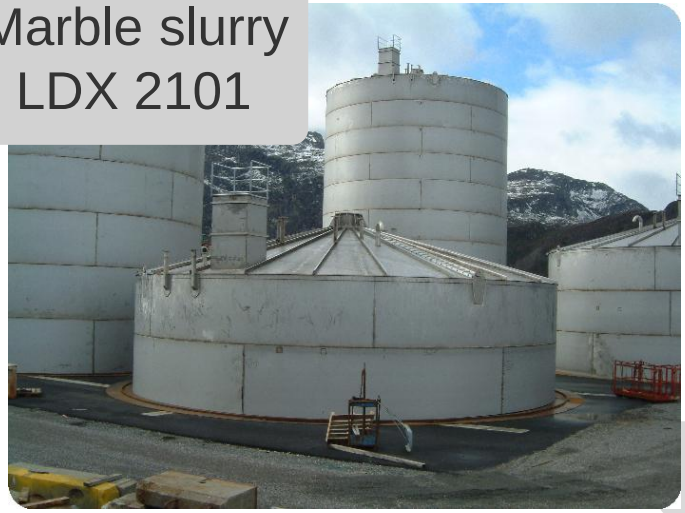


Molasses LDX 2101

Wine tanks LDX 2101 & 2304

Bio fuel –
2304 + LDX 2101

Zinc leaching – 2507



Marble slurry
LDX 2101

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Largest pulp digester worldwide

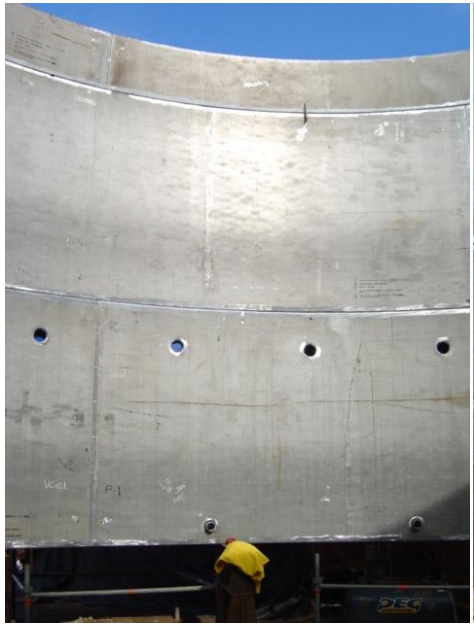
Veracel pulp & paper plant, Brazil (Stora + Aracruz)

Fabricatior: Montcalm, Engineering: Andritz

Filler metals:

- 4 500 kg of CN 22/9 N PW-FD
- 1 200 kg of FOX CN 22/9 N
- 700 kg of CN 22/9 N-IG
- 450 kg of CN 23/12 PW-FD
- 650 kg of EAS 2 PW-FD
- 600 kg of EAS 4 PW-FD
- 9 000 kg of other stainless steel coated electrodes, rods and solid wires
- 15 000 kg of carbon steel coated electrodes, rods, flux cored and solid wire

Base metal: Duplex stainless steel UNS S31803



- Welded with: Avesta FCW 2205-PW
- Diameter: 0.045'' (1.2 mm)
- Height: 184 ft / 56 m, dia. 34.8 ft / 10.6 m
- Wall thickness: 1.3-2.17" (33-55 mm)
- Horizontal 2G, vertical 3G
- acc. to ASTM A 923 B

Some lean duplex pulp & paper applications

Avesta FCW LDX 2101-PW

TCF bleaching – hydrogen peroxide

LDX 2101®, Smurfit Kappa, Sweden

Blow tank – LDX 2101, Sweden

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Digesters

Continuous, 220

Sulphite
2205, NA

Super Batch, 2205
Thailand

2205, Botnia Mill, Uruguay

2205, Jiang Lin, China

2205, Veracel, Brazil

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Heavy transport road tankers

Avesta FCW LDX 2101-PW

LNG tankers outer hull made of LDX 2101, Spain
Improved quality, cost-efficiency and reduced weight

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Properties all weld metal

Avesta 2205 grades – mechanical properties, all weld metal

		Tensile strength					Impact toughness [J]			Hardness	
Type	**Name**	**$Rp_{0.2}$ [MPa]**	**Rm [MPa]**	**Rm [MPa]**	**A_5 [%]**	**A_5 [%]**	**20°C**	**-40°C**	**-50°C**	**Hv10**	
SMAW	2205 Bas	660	830	690	26	20	115	75	55	270	290
SMAW	2205-2D	640	825	690	26	20	55	40	-	280	290
SMAW	2205-3D	610	800	690	25	20	55	40	-	280	290
SMAW	2205-4D	630	820	690	25	20	45	35	-	280	290
SMAW	2205-PW	690	870	690	26	20	55	45	35	280	290
GMAW	2205	570	780	690	30	20	150	115	80	280	290
GTAW	2205	620	800	690	28	20	220	210	200	265	290
SAW	2205*	600	800	690	27	20	100	70	-	275	290
FCAW	FCW-2D 2205	600	800	690	27	20	60	40	-	280	290
FCAW	FCW 2205-PW	600	800	690	27	20	80	55	-	280	290

Properties – Welding consumables

Typical weldment properties

Steel grade	ASTM	EN	Welding method	Pitting corrosion[1] CPT (°C)	Weldment mechanical properties (typical)		
					Rm (MPa)	Impact (J)	
						+20°C	-40°C
LDX 2101	S32101	1.4162	GMAW	> 6[2]	725	150	110
			FCAW	> 6[2]	725	63	45
2304	S32304	1.4362	GMAW	> 10	640	150	110
			FCAW	> 10	700	50	40 (-20°C)
2205	S32205	1.4462	GMAW	> 22	780	150	110
			FCAW	> 25	770	60	40
2507	S32750	1.4410	GMAW	> 35	850	140	50 (-46°C)
			FCAW	> 35	890	60	45

1) ASTM G 48-E
2) ASTM G 150

Weld repair of cast in foundries – FCAW

Success story at AMPO Valves Idiazabal, Spain

- Replacing GMAW to avoid porosity
- PW wires - do not have to turn large pieces in best position
- High productivity

Customer testing – repair welding in foundry

FCAW with Ø1.2 mm FCW 2507/P100-PW NOR

Delivers much material to offshore industry

Have struggled with procedure testing with other products

32.5 V, 237-243 A, 7-9.5 mm/s welding speed

Solution annealing 1120°C for 2.5 min/mm + water quenching

Impact toughness at -46°C: 76, 79, 75 J

Weld metal ferrite content: 45 ± 5%

ASTM G48 Method A approved at 50°C / 24 h

Some possible material combinations

- Mild steels
- Fine grained steels
- High temperature steels
- Low temperature steels

- Martensitic/Ferritic Cr-steels
- Austenitic CrNi(Mo)-steels
- Duplex steel
- Nickel-base alloys

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- Ferritic Cr-steels
- Sort martensitic CrNi-steels

- Austenitic CrNi(Mo)-steels
- Duplex steel
- Nickel-base alloys

Dissimilar welding

*P12 = Ni Cr 22 Mo 9 Nb, Ni Cr Mo-3
*P16 = Ni Cr 23 Mo 16, Ni Cr Mo-13

Grade	LDX 2101	2304	2205	2507	304	316	254 SMO "6Mo"	Carbon Steel
LDX 2101	23 7 N L 22 9 3 N L	23 7 N L 22 9 3 N L	22 9 3 N L	25 9 3 Cu N L	23 7 N L 23 12 2 L 23 12 L	23 7 N L 23 12 2 L	P12* P16*	23 7 N L 23 12 2 L 23 12 L
2304	23 7 N L 22 9 3 N L	23 7 N L 22 9 3 N L	22 9 3 N L	25 9 3 Cu N L	23 7 N L 23 12 2 L 23 12 L	23 7 N L 23 12 2 L	P12* P16*	23 7 N L 23 12 2 L 23 12 L
2205	22 9 3 N L 23 7 N L	22 9 3 N L	22 9 3 N L	25 9 3 Cu N L	22 9 3 N L 23 12 2 L 23 12 L	22 9 3 N L 23 12 2 L	P12* P16*	22 9 3 N L 23 12 2 L 23 12 L
2507	25 9 3 Cu N L	25 9 3 Cu N L	25 9 3 Cu N L	25 9 3 Cu N L	25 9 3 Cu N L 23 12 2 L 23 12 L	25 9 3 Cu N L 23 12 2 L	P12* P16*	25 9 3 Cu N L 23 12 2 L 23 12 L

Dissimilar welding

Testing in accordance with BS 4515-2 + client specification

Forging grade A182 F53 to pipe A790 UNS S32760

GTAW weld root

Avesta FCAW 2507/P100-PW NOR

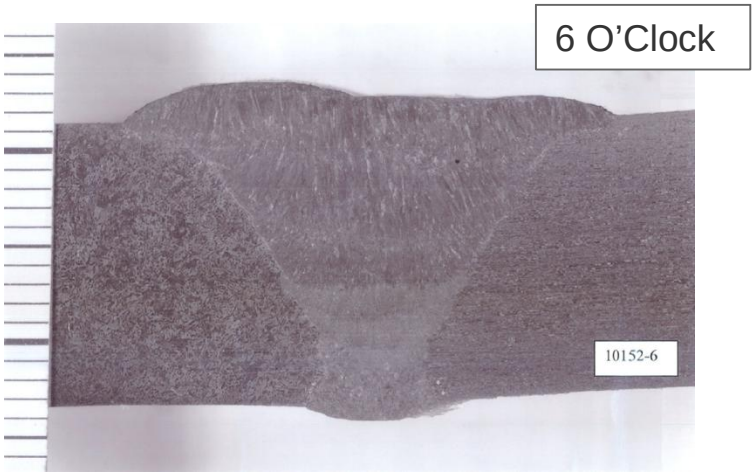
5G (PF) position

All testing approved:

Cross-tensile tests, requirement Rm ≥ 750

Hardness HV 10, requirement HV 10 ≤ 350

Impact toughness Charpy KV, as info at -40°C
(measured mean value 88 J)



Welding duplex steels of similar composition

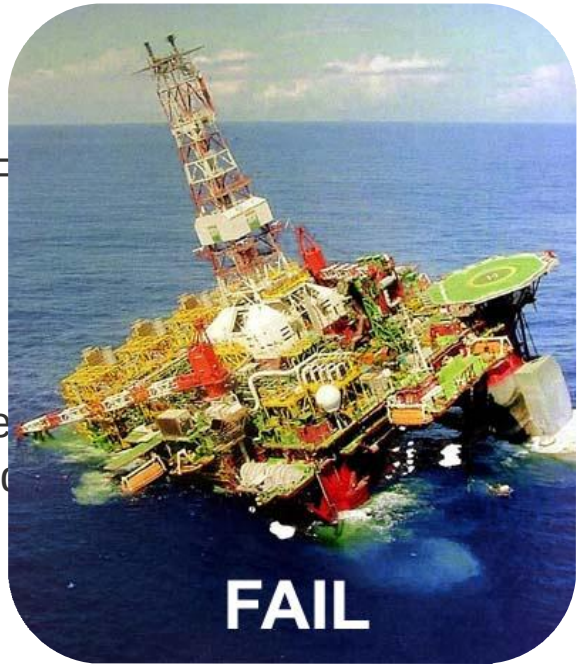
Steel grades	Böhler	Avesta
LDX 2101, S32101, 1.4162, S32001, 19D	CN 24/9 or CN 22/9	LDX 2101 or 2304 or 2205
ASTM 329	CN 22/9	2205
AL 2003 (UNS 32003)	CN 22/9	2205
3RE60 (S31500)	CN 22/9	3RE60 or 2205
1.4363, S32304, URANUS 35N, SAF 2304	CN 24/9 or CN 22/9	2304 or 2205
1.4662, LDX 2404, S82441	CN 22/9, CN 25/9	2205, 2404, 2507
1.4462, S32205, SAF 2205, Uranus 45N, Remanit 4462, 1903SC, AF22, CS22, Falc 223, SM 22Cr, NKCr22	CN 22/9	2205
1.4410, S32750, SAF 2507, 1.4510, Zeron 100, DP-3W, S32760, Uranus 52M+	CN 25/9 (CuT)	2507/P100

How to avoid unexpected phenomena?

Use QA system for welding in EN ISO 3834-(1-3)
EN-ISO 15614 – establishing welding procedure

- preliminary welding procedure specification (pWP
- welding procedure qualification record (WPQR)
- welding procedure specification (WPS)

Based on test welding (pWPS) and results from testing (WPQR) of specific weld, responsible welding enginee creates approved WPS that welders shall follow in fiel



Further train welders and operators on how to weld involved grades, necessity of post-weld cleaning for corrosion resistance and how they can minimize needed pickling time by handling material properly

voestalpine
ONE STEP AHEAD.

Main challenges when welding superduplex

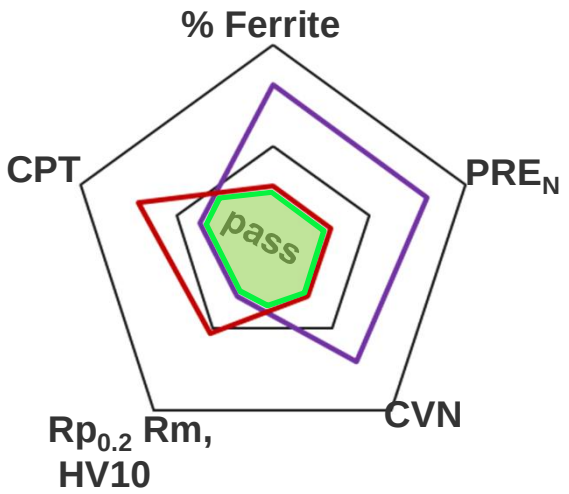
From voestalpine Böhler Welding's point of view

Risk of sigma phase formation (intermetallics)

- Negative for corrosion resistance and impact toughness
- Limits heat input and interpass temperature

Corrosion testing ASTM G48

- Pickling required
- Specified test temperature too high
- Pure argon often used as backing gas



Impact toughness

- More productive slag-shielded methods
- High austenite content good, but often limited to 35–65%

Conservative specifications limit use of e.g. some methods and gases

Increasingly conservative specifications

Main challenges when welding superduplex

From Böhler Welding Group's point of view

Corrosion testing of superduplex (ASTM G48)

- Pure argon often used
- Best backing gas not always allowed

Impact toughness

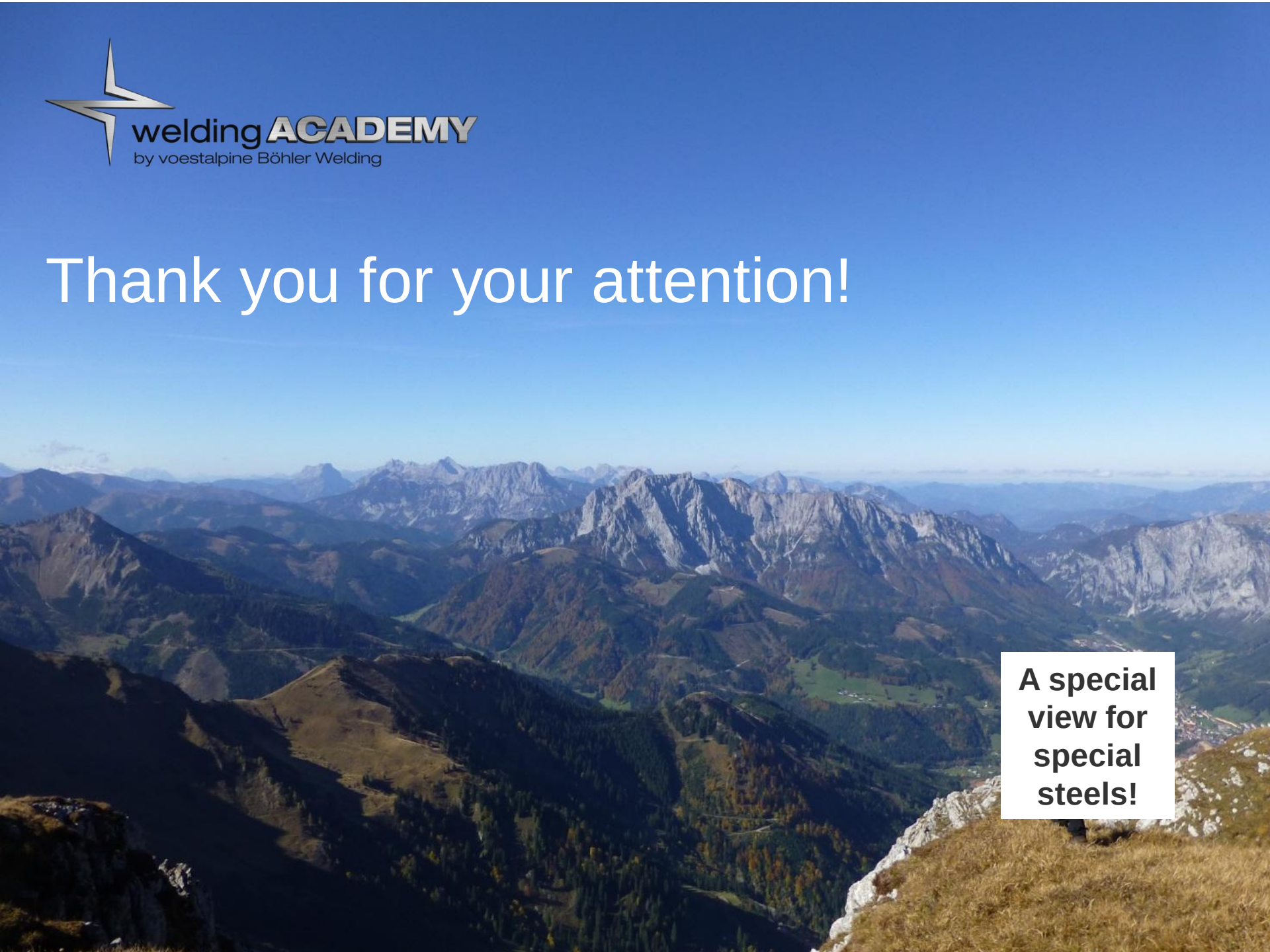
- More productive slag-shielded methods
- High austenite content good, but often limitefd to 35-65%

Specifications limits use of

- FCAW (e.g. Total, Petrobras)
- Nitrogen in backing gas (e.g. Total)
- Hydrogen in nitrogen-based backing gas (e.g. Shell)

welding ACADEMY
by voestalpine Böhler Welding

Thank you for your attention!



welding ACADEMY
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Thank you!

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