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Industry Standard Welding Procedures Software for AWS and ASME Codes

Welding Practice
for the Sandvik Duplex Stainless Steels
SAF 2304, SAF 2205 and SAF 2507

Presented by

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Key Points

- Metallurgical Considerations
- Welding Processes
- Composition differences Base Metal and Filler Metal
- Good Mechanical and Corrosion Properties of Welds
- Importance of Heat Input and Interpass Temperature
- Role of Nitrogen
- Post Weld Cleaning
- Dissimiliar Joining
- Joint Design

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Characteristics of Duplex stainless steels

- **Excellent resistance to stress corrosion cracking**
- **Very high mechanical strength**
- **Excellent resistance to pitting and crevice corrosion**
- **High resistance to general corrosion in a variety of environments**
- **Low thermal expansion**
- **High resistance to erosion corrosion and corrosion fatigue**
- **Good weldability**
- **Lower life cycle cost**

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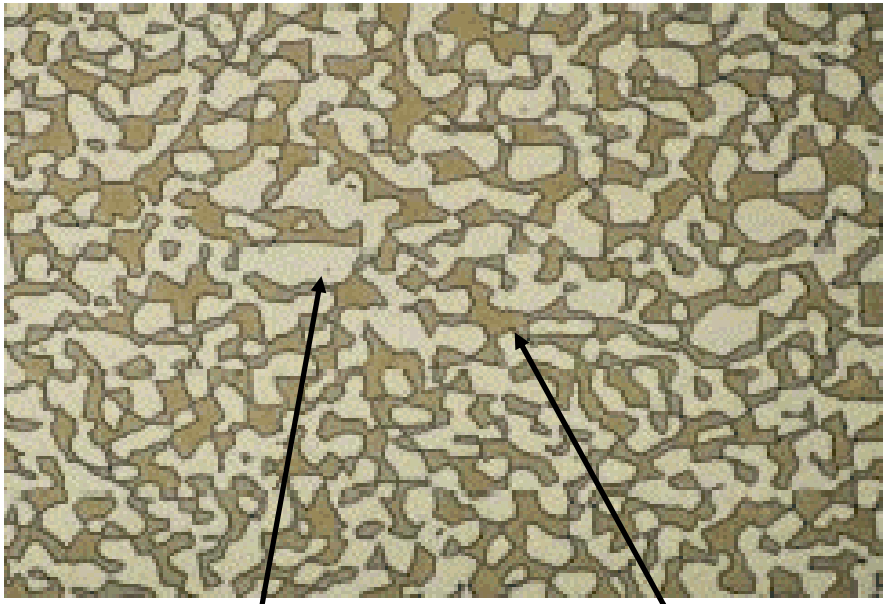
Duplex microstructure



- The austenite islands (light) are embedded in a continuous ferrite (dark) matrix.
- The duplex microstructure typically contains 45-65% austenite and 35-55% ferrite.

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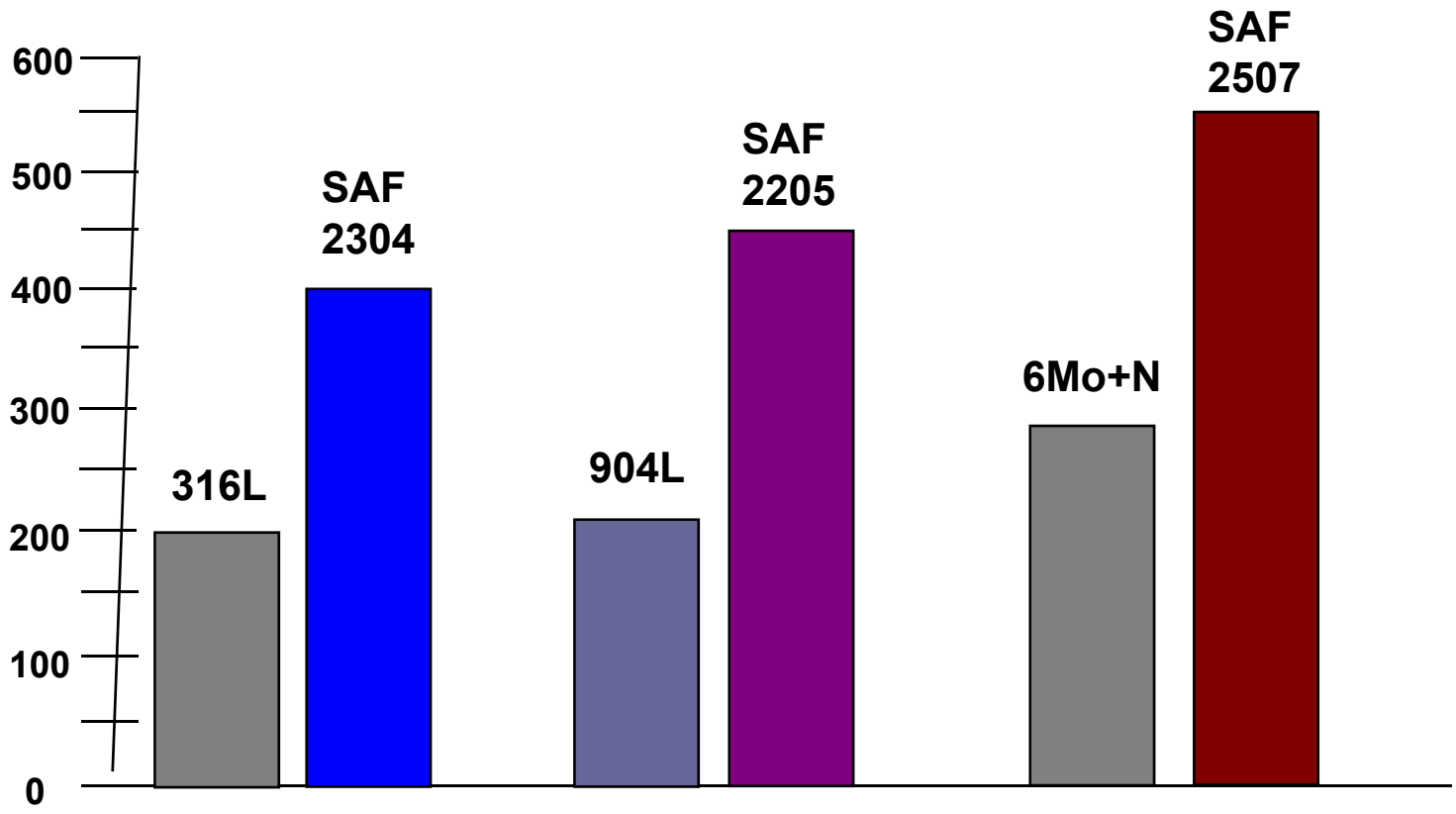
Yield Strength 0,2%
Austenitic vs Duplex Stainless Steel



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Coefficient of expansion
$(x10^{-6})°C^{-1}$

Austenitic stainless steels	**approx. 17**
Duplex stainless steels	**approx. 13**
Carbon steel	**approx. 11,5**

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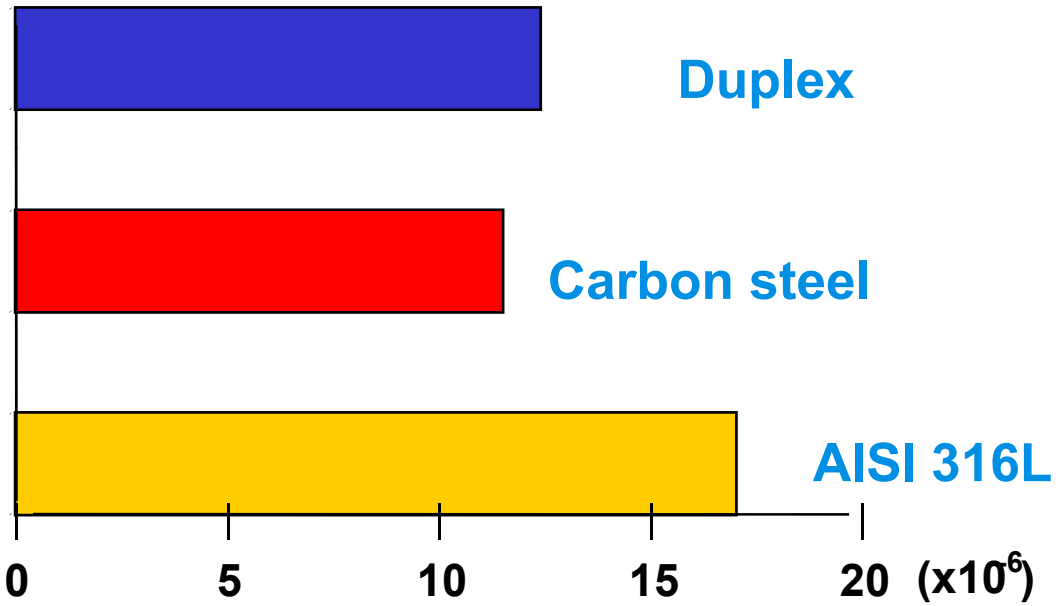
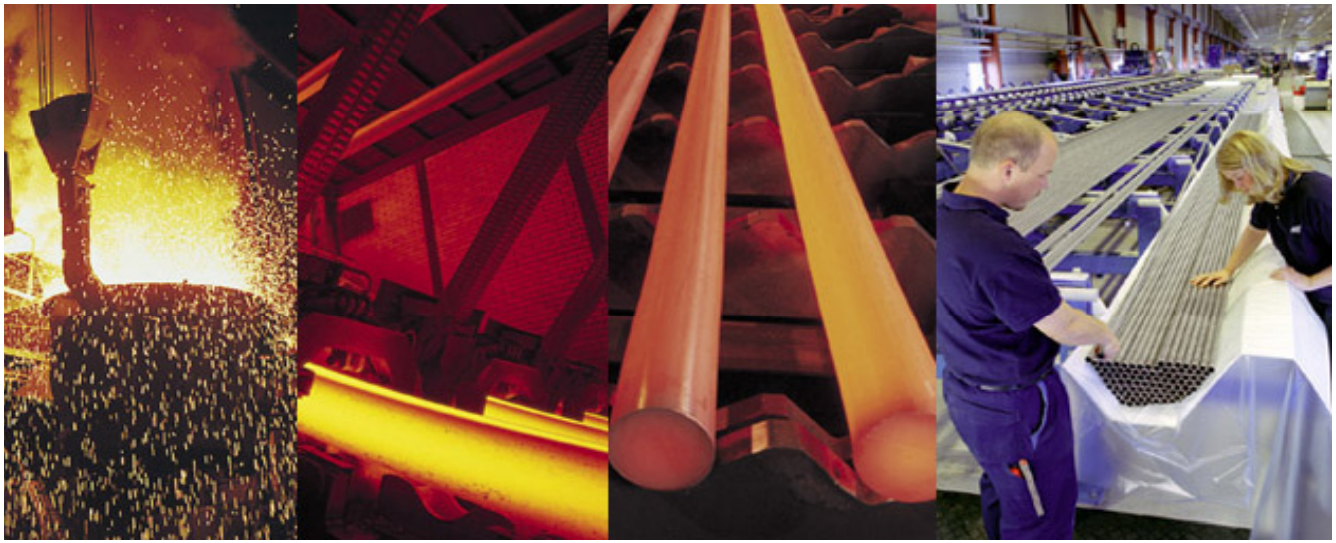
Thermal expansion, per °C (20-100°C)



Solidification mechanism of Duplex stainless steel



- As duplex stainless steels solidify the grain structure transform from a fully ferritic material to a balanced austenite and ferrite microstructure

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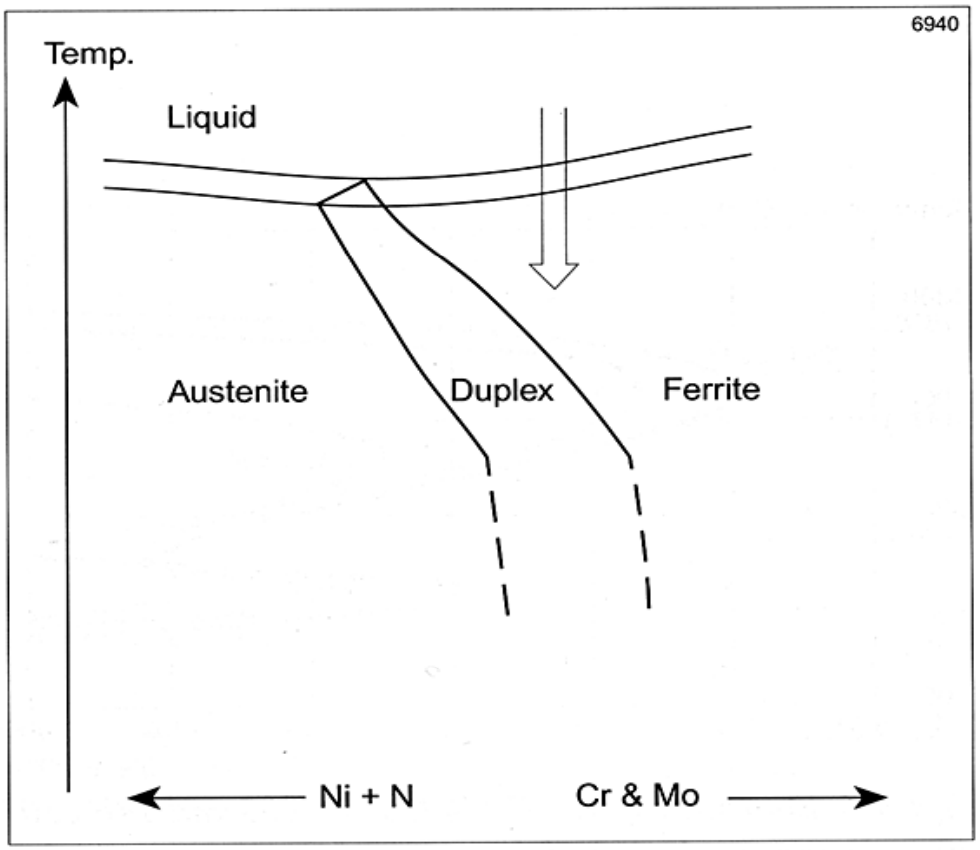
Solidification mechanism of a Duplex Stainless Steel



HAZ of weld in SAF 2507

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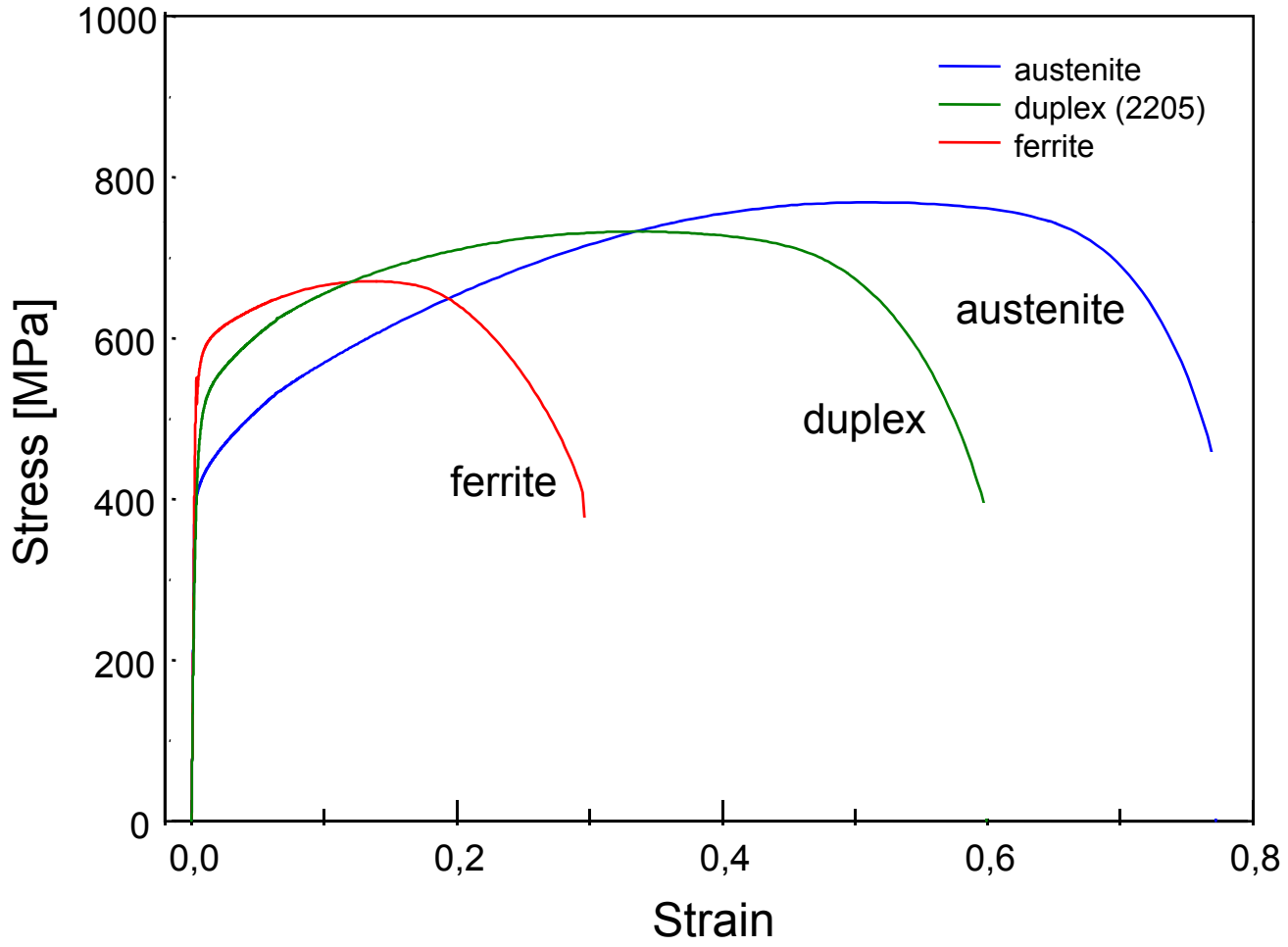
Stress strain curves
Austenite, ferrite and duplex



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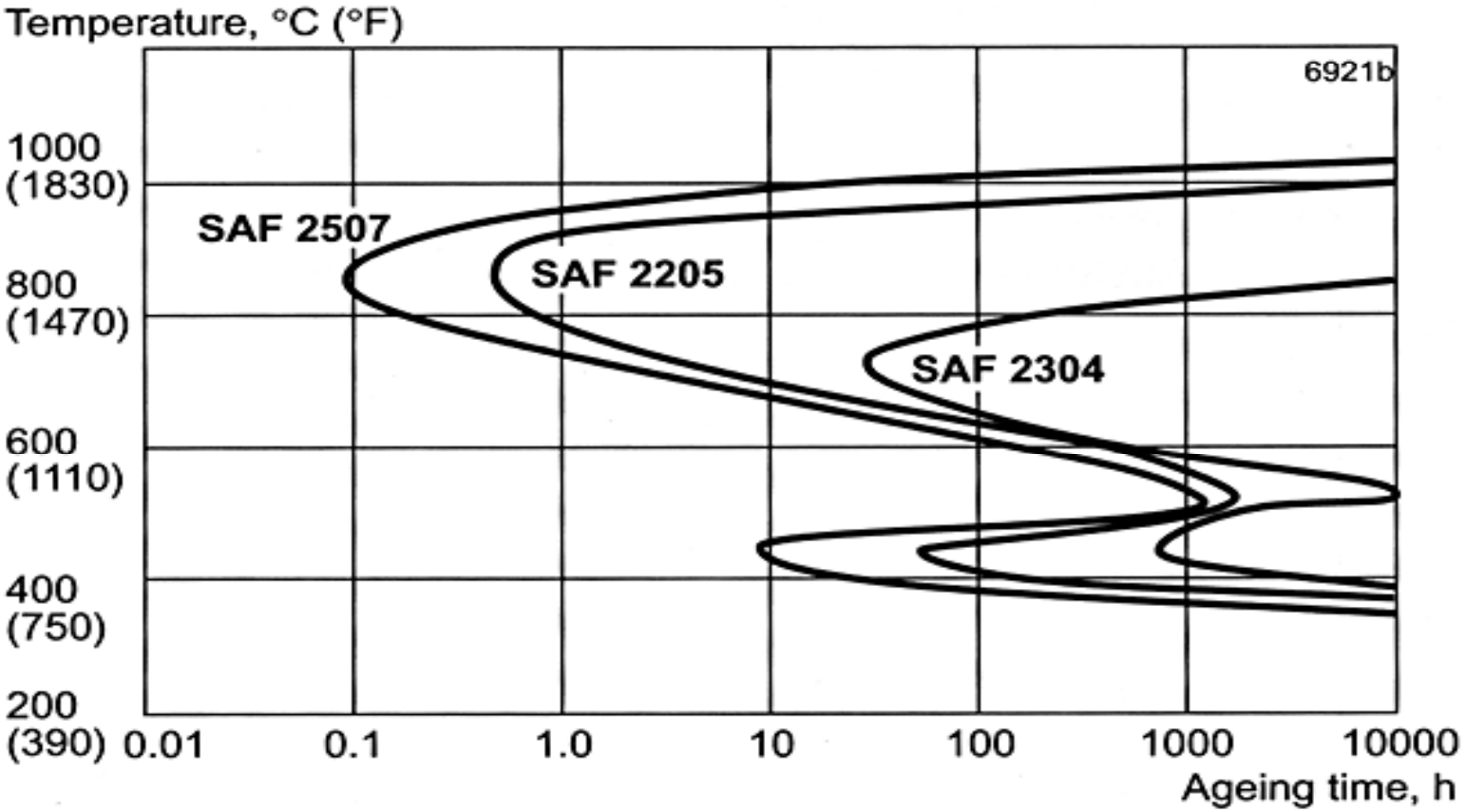
Reasons for the high strength of duplex stainless steels

- Content of ferrite
- Fine grained structure
- Nitrogen

Embrittling of Duplex Stainless Steels



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Welding Processes

Conventional Processes

- GTAW
- GMAW
- SAW
- SMAW
- FCAW

Avoid

- Autogenous
- Low Energy Processes
- Or Perform PWHT

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Filler Metals for the Welding of Duplex Stainless Steels

Parent metal Sandvik	Welding process	Filler metal Sandvik	Chemical composition, wt-% C max.	Si	Mn	P max.	S max.	Cr	Ni	Mo	N	Ferrite All weld metal, %
SAF 2304	TIG, MIG, SAW	23.7.L	0,020	0,4	1,5	0,020	0,015	23	7	-	0,14	30-40
	MMA	23.8.LR	0,030	<0,9	0,5	0,030	0,025	25	9	-	0,12	30-40
SAF 2304	TIG, MIG, SAW	2209	0.020	0,5	1,6	0,020	0.015	22,5	8	3	0,14	30-40
and	MMA	2209-16,17	0,030	<1,0	0,8	0,030	0,025	22,5	9	3	0,12	30-40
SAF 2205		2209-15	0,04	<0,5	0,8	0,030	0,025	22	9	3	0,15	30-40
	FCAW	2209LT	0.030	<1.0	1.5	0.030	0.025	22.5	9	3	0.15	30-40
SAF 2507	TIG, (MIG), SAW	25.10.4.L	0,020	0,3	0,4	0,020	0,020	25	10	4	0,25	30-40
	MMA	25.10.4.LR	0,030	0,5	0,7	0,030	0,025	25	10	4	0,25	30-40
		25.10.4.LB	0,040	0,4	0,9	0,030	0,025	25,5	9,5	4	0,25	30-40

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Mechanical properties of the Duplex Stainless Steels

Sandvik	UNS	Yield strength 0,2% offset MPa min.	Yield strength 0,2% offset ksi. min.	Yield strength 1,0% offset MPa min.	Yield strength 1,0% offset ksi. min.	Tensile strength MPa min.	Tensile strength ksi. min.	Elong. A5 % min.	Hardness Vickers approx.
SAF 2304	S32304	400	58	450	65	600-820	87-119	25	230
SAF 2205	S31803	450	65	500	73	680-880	99-128	25	260
SAF 2507	S32750	550	80	640	93	800-1000	116-145	25	290

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Mechanical Properties of All Weld Metal

Filler metal Sandvik	Welding process	$R_{po,2}$ MPa	$R_{p1,0}$ MPa	R_m MPa	A_5 %	Z %	Impact strength, J RT	-40°C
23.7.L	TIG	525	595	708	34	58	171	156
23.7.L	SAW[1)]	503		671	34		101	72
23.8.LR	MMA	627	681	773	26	46	62	46
22.8.3.L	TIG	610		760	28		207	160
22.8.3.L	SAW[1)]	578	664	775	33	53	139	84
22.9.3.LR	MMA	512		734	33		52	44
22.9.3.LT	FCAW	620	-	816	30	44	56	43
25.10.4.L	TIG	672		851	28	64	150	116
25.10.4.L	SAW[1)]	687	757	878	27	47	91	64
25.10.4.LR	MMA	645		850	28		46	33

[1)]Using Sandvik 15W flux

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Mechanical properties of welded joints. Cross-weld tensile test

Parent metal Sandvik	Filler metal Sandvik	Welding process	$R_{p0.2}$ min. MPa	typical
SAF 2304	23.7.L	TIG	400	446
	23.7.L	SAW[1)]	400	452
	23.8.LR	MMA	400	462
SAF 2205	22.8.3.L	TIG	450	553
	22.8.3.L	SAW[1)]	450	588
	22.9.3.LR	MMA	450	588
	22.9.3.LT	FCAW	450	585
SAF 2507	25.10.4.L	TIG	550	645
	25.10.4.L	SAW[1)]	550	628
	25.10.4.LR	MMA	550	628

[1)]Using Sandvik 15W flux

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Charpy-V impact strength of welded joints

Parent metal Sandvik	Filler metal Sandvik	Welding process	Impact energy, J RT	-40°C
SAF 2304	23.7.L	TIG	213	74
	23.7.L	SAW[1)]	105	17
	23.8.LR	MMA	46	38
SAF 2205	22.8.3.L	TIG	282	133
	22.8.3.L	SAW[1)]	54	42
	22.9.3.LR	MMA	52	43
	22.9.3.LT	FCAW55	44	
SAF 2507	25.10.4.L	TIG	110	78
	25.10.4.L	SAW[1)]	100	58
	25.10.4.LR	MMA	58	39

[1)]Using Sandvik 15W flux

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Typical CPT Values from G-48A Tests for Parent Metals and Welded Joints

Sandvik	Filler metal	Welding process	Shielding gas	Root gas	CPT °C
SAF 2304					~15
All weld metal	23.7.L	TIG	Ar	-	<15
Joint	23.7.L	TIG	Ar	Ar	<15
Joint	23.7.L	SAW[1)]	-	-	<15
Joint	23.8.LR	MMA	-	-	<15
SAF 2205					30 ← PM
All weld metal	22.8.3.L	TIG	Ar	-	20-23
Joint	22.8.3.L	TIG	Ar	Ar	20-23
Joint	22.8.3.L	TIG	Ar - 2% N_2	90 N_2 + 10 H_2 (or pure N_2)	23-25
All weld metal	22.8.3.L	SAW[1)]	-	-	20-25
Joint	22.8.3.L	SAW[1)]	-	-	20-25
All weld metal	22.9.3.LR	MMA	-	-	20-25
Joint	22.9.3.LR	MMA	-	-	20-25
SAF 2507					80
	Autogenous TIG welding				40
All weld metal	25.10.4.L	TIG	Ar	-	40-45
Joint	25.10.4.L	TIG	Ar	Ar	40-45
Joint	25.10.4.L	TIG	Ar	90 N_2 + 10 H_2 (or pure N_2)	40-50
Joint	25.10.4.L	TIG	Ar + 2% N_2	90 N_2 + 10 H_2 (or pure N_2)	45-55
All weld metal	25.10.4.L	SAW [1)]	-	-	40-50
Joint	25.10.4.L	SAW [1)]	-	-	40-50
All weld metal	25.10.4.LR	MMA	-	-	40-50
Joint	25.10.4.LR	MMA	-	-	40-50

[1)] Using Sandvik 15W flux

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Quench annealing of Duplex Steel welds

Sandvik	Holding temperature °C	Quenching media
SAF 2304	930 - 1050	Water
SAF 2205	1020 - 1100	Water
SAF 2507	1080 - 1120	Water

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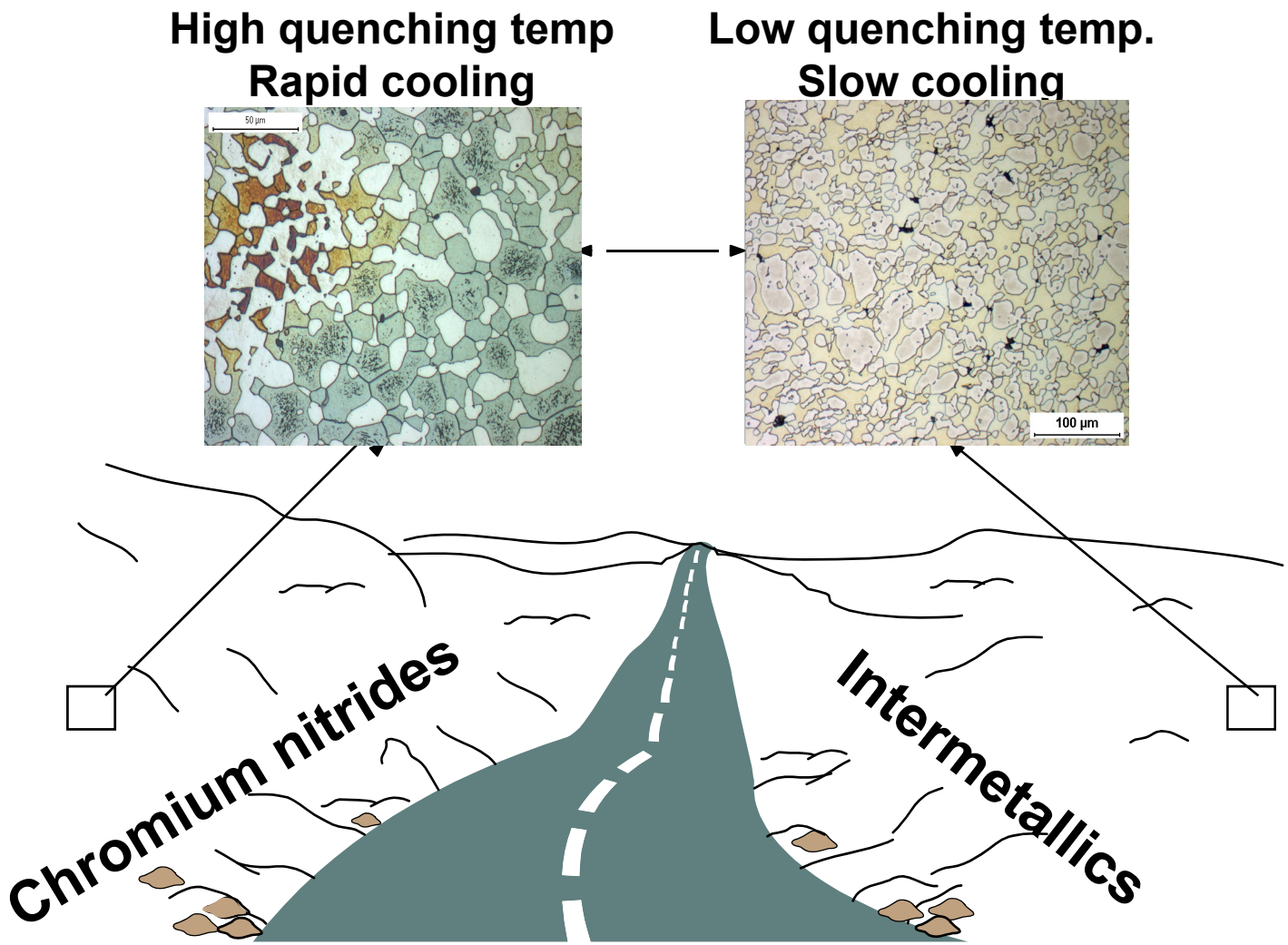
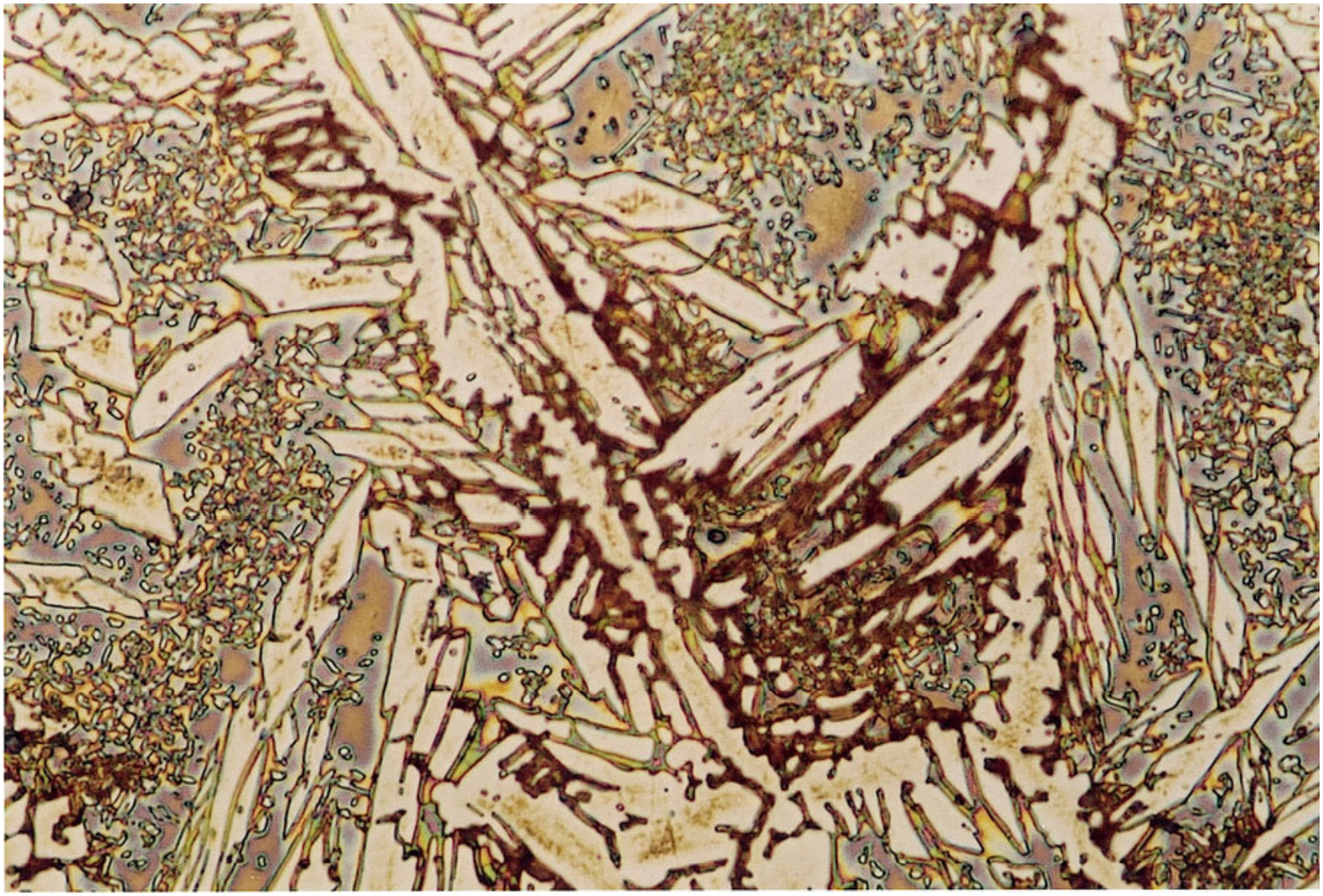

High quenching temp
Rapid cooling
Low quenching temp.
Slow cooling
50 µm
100 µm
Chromium nitrides
Intermetallics

Intermetallic phase



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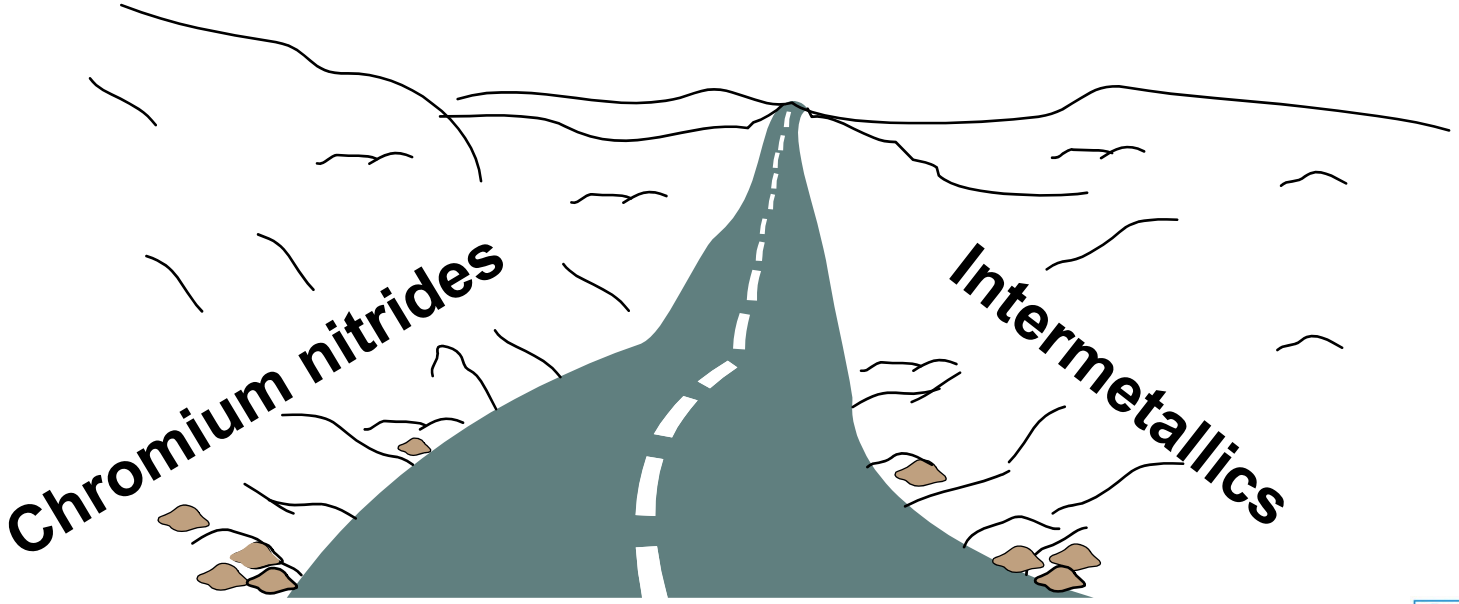
Recommended heat input

Steel	Heat input	Interpass temperature
SAF 2304	0,5 - 2,5 kJ/mm	<250°C
SAF 2205	0,5 - 2,5 kJ/mm	<250°C
SAF 2507	0,2 - 1,5 kJ/mm	<150°C



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Welding recommendations

Sandvik	Heat input kJ/mm	Interpass temperature °C
SAF 2304	0,5 - 2,5	<250
SAF 2205	0,5 - 2,5	<250
SFA 2507	0,2 - 1,5	<150

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The roll of Nitrogen

- **Nitrogen is a very important alloying element in DSS**
  - ✓ **Improves corrosion resistance**
  - ✓ **Improves austenite reformation**

- **At TIG welding, the loss of nitrogen is compensated for by using Ar + 1 - 2%N2 as a shielding gas**

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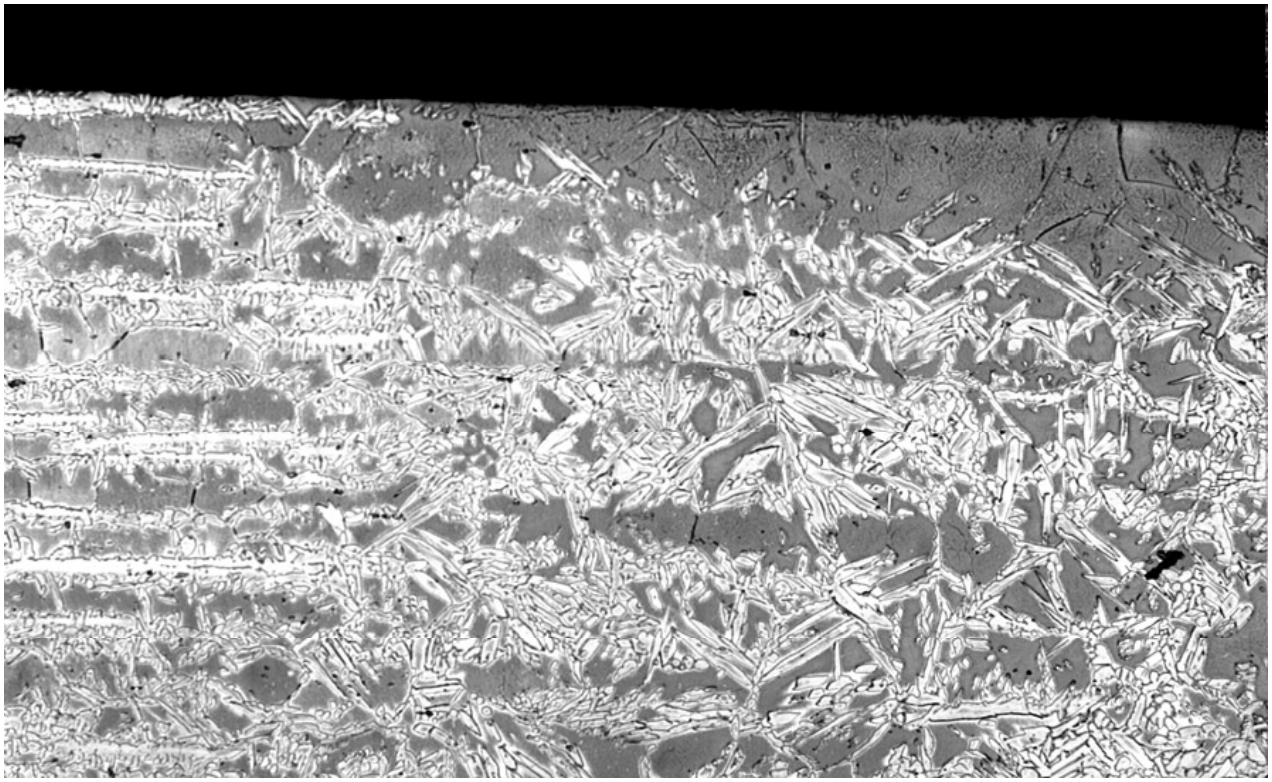
Ferritic area in SAF 2507 weld owing to the loss of nitrogen in fusion line



Shielding gas Ar 99,99%

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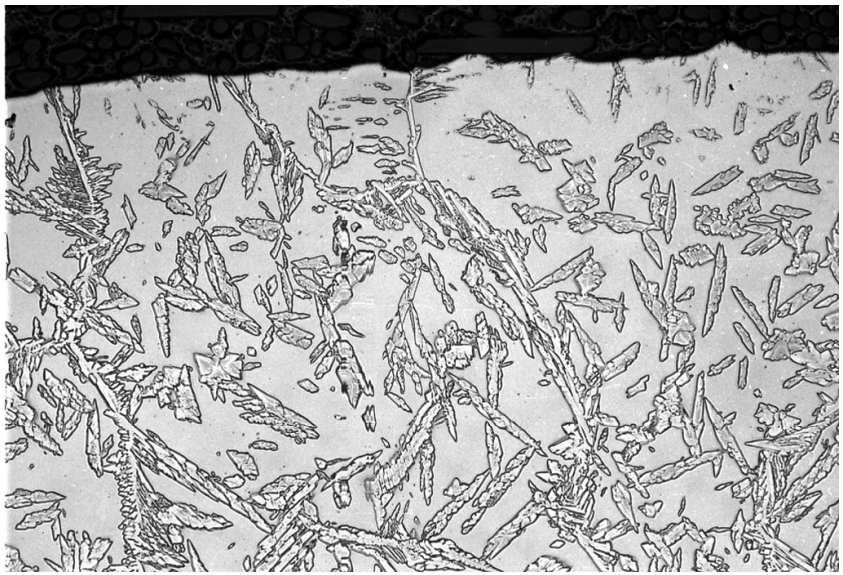
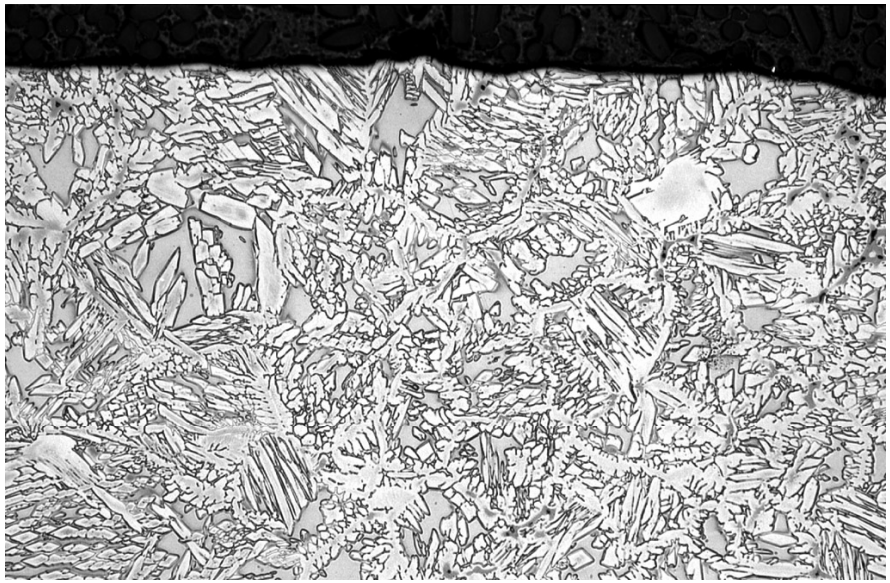
Nitrogen addition to the shielding gas



Ar 99,99%



Ar + 5% N_2

Preferred,
typically 2% N2

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Ferrite content in TIG-welds, SAF 2507

Filler metal Sandvik	Shielding gas	Root gas	Ferrite content, vol-% ± error with 95% confidence interval	
25.10.4.L	Ar	Ar	55 ± 4,5	
25.10.4.L	Ar	90% N_2 + 10% H_2	59 ± 4,0	For Root Pass
25.10.4.L	Ar + 5% N_2	90% N_2 + 10% H_2	33 ± 4,0	

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Nitrogen Content in TIG welds of SAF 2507. N=0,25% in the filler metal

Filler metal Sandvik	Shielding gas	Root gas	Weight-% N in deposit
25.10.4.L	Ar	90% N_2 + 10% H_2	0,23
25.10.4.L	Ar + 3% N_2	90% N_2 + 10% H_2	0,27
25.10.4.L	Ar + 6% N_2	90% N_2 + 10% H_2	0,33

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GMAW SHIELDING GASES

- **General recommendations:**
  - ✓ **Short arc welding gives very convex beads.**

    Ar+30 He+1 O2

  - ✓ **Spray arc welding**

    Ar+30 He+1 O2 (22Cr duplex)

    Ar+2 CO2(Super duplex)

  - ✓ **Pulsed arc welding**

    Ar+30 He+1 O2 (22Cr duplex)

    Ar(99,996%) for super duplex

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Nitrogen Analysis from the Top of a TIG weld

	% Nitrogen in position (o'clock)						Analysis at
	3	5	6	7	11	12	
Welder No. 1	0,17	0,18	0,15	0,16	0,19	0,19	Top side
Welder No. 2	0,18	-	0,19		0,19	-	Top side
	0,20	-	0,21		0,20	-	Root side
Welder No. 3	0,22	-	0,21		0,20	-	Top side
	0,21	-	0,21		0,20	-	Root side

In all cases the filler metal had a nitrogen content of 0,25%

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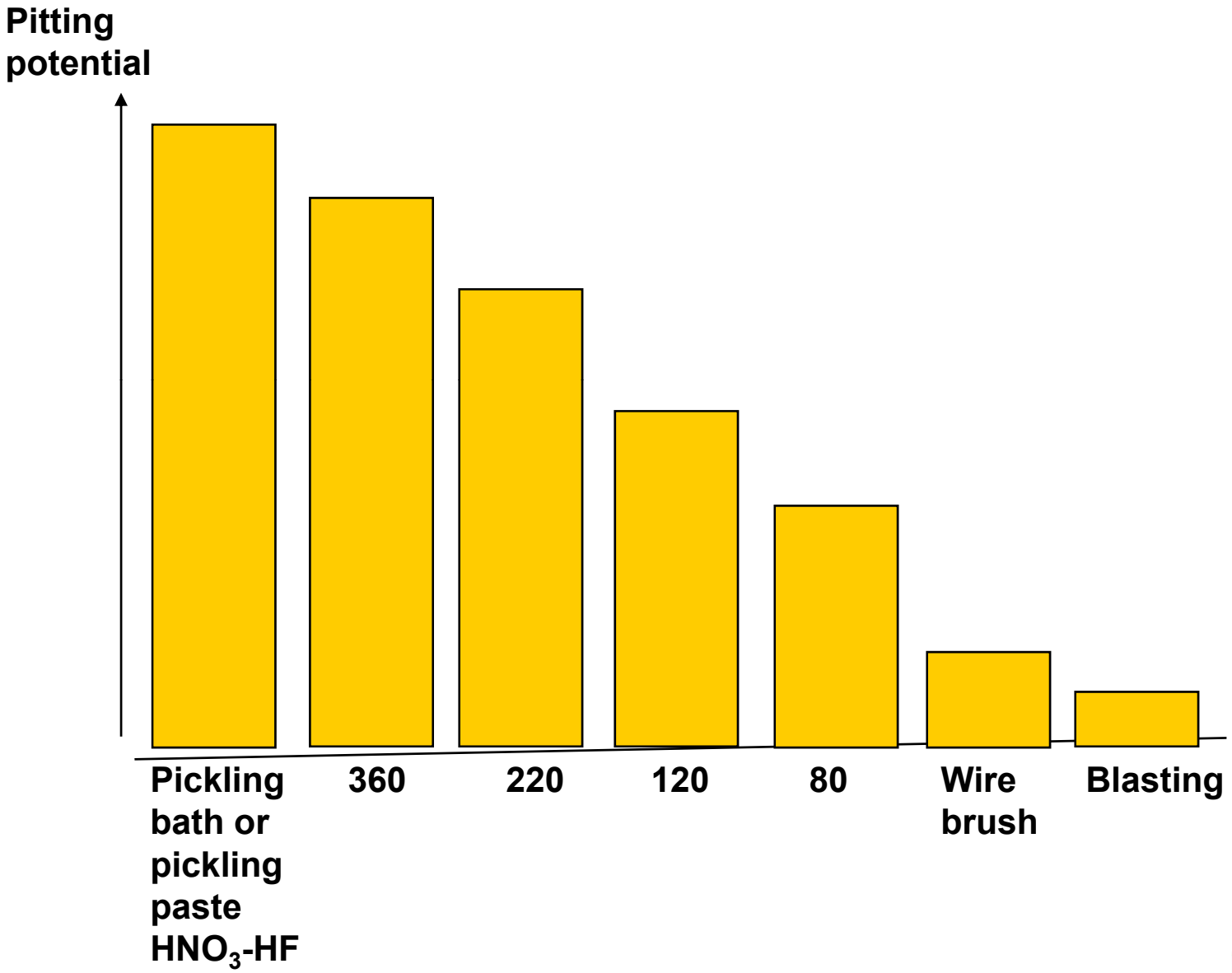
Stress relieving temperatures

325 ± 25°C for 10 hours

Post Weld Cleaning



Dissimilar Joints

SAF	Carbon steel	AISI 200 and 300-series	AISI 904L, Sanicro 28, 254 SMO, etc.
2304	22.8.3.L 22.9.3.LR 22.9.3.LT	22.8.3.L 22.9.3.LR 22.9.3.LT	22.8.3.L 22.9.3.LR 22.9.3.LT
2205	22.8.3.L 22.9.3.LR 22.9.3.LT	22.8.3.L 22.9.3.LR 22.9.3.LT	22.8.3.L 22.9.3.LR 22.9.3.LT
2507	25.10.4.L 25.10.4.LR	25.10.4.L 25.10.4.LR	Sanicro 60 Sanicro 60

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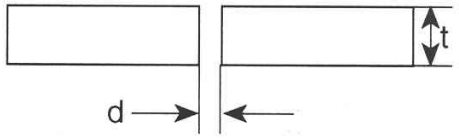
Joint preparation
One sided butt welding

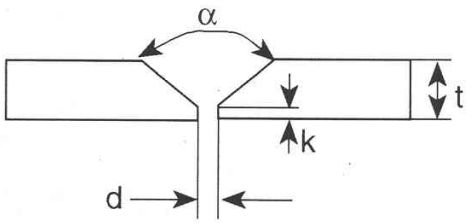
Square groove

	t mm	d mm
MMA	<3	1–2
TIG	<3	1–2
MIG	<3	1–2



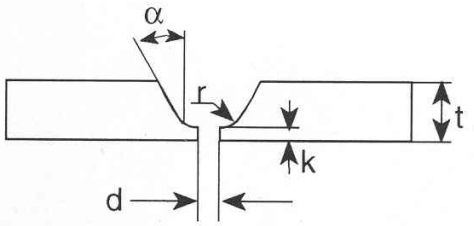
V-groove

	t mm	d mm	k mm	α
MMA	3–15	2–3	1–2	60–70°
TIG	2.5–8	2–3	1–2	60–70°
MIG	3–12	2–3	1–2	60–70°
SAW*	4–12	2–3	1–2	70–90°



U-groove

	t mm	d mm	k mm	r mm	α
MMA	>12	1–2	2–3	6	15°
TIG	>6	1–2	1–2	6–8	15°
MIG	>12	1–2	2–3	6	15°
SAW*	>10	1–2	1–3	6–8	15°



*Root pass with TIG, MIG or MMA. SAF 2507: Contact Sandvik for advice.

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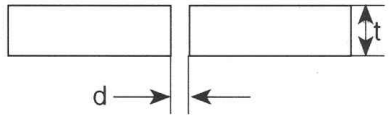
Joint preparation
Butt welding from both sides

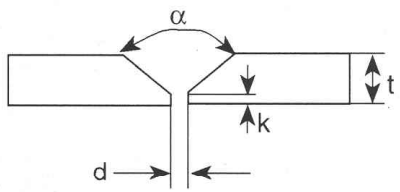
Square groove

	t mm	d mm
MMA	3–4	1.5–3
TIG	3–5	1.5–3
MIG	3–6	1.5–3



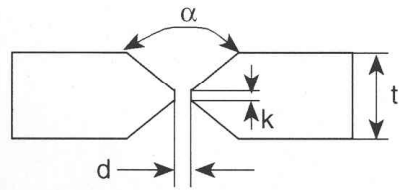
V-groove

	t mm	d mm	k mm	α
MMA	4–15	1–3	1–2	60–70°
TIG	2.5–8	1–3	1–2	60–70°
MIG	5–12	1–3	1–2	60–70°



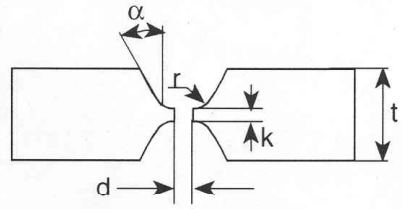
Double V-groove

	t mm	d mm	k mm	α
MMA	>10	1.5–3	1–3	60–70°
MIG	>10	1.5–3	1–3	60–70°
SAW	>10	0	3–5	90°

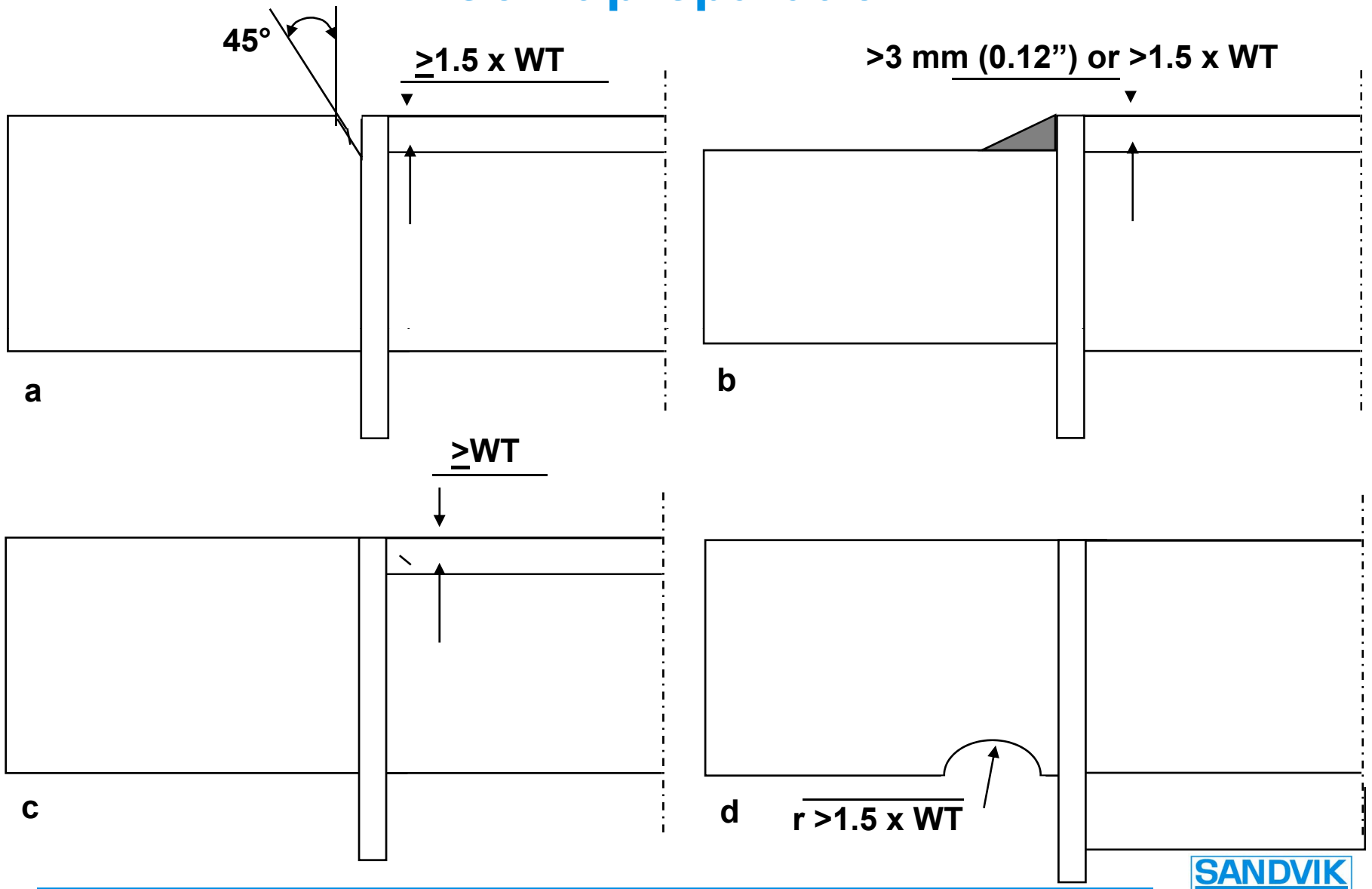


Double U-groove

	t mm	d mm	k mm	r mm	α
MMA	>25	1–3	1–3	6–8	10–15°
SAW	>25	0	3–5	6–8	10–15°



Tube to tube sheet welding.
Joint preparation



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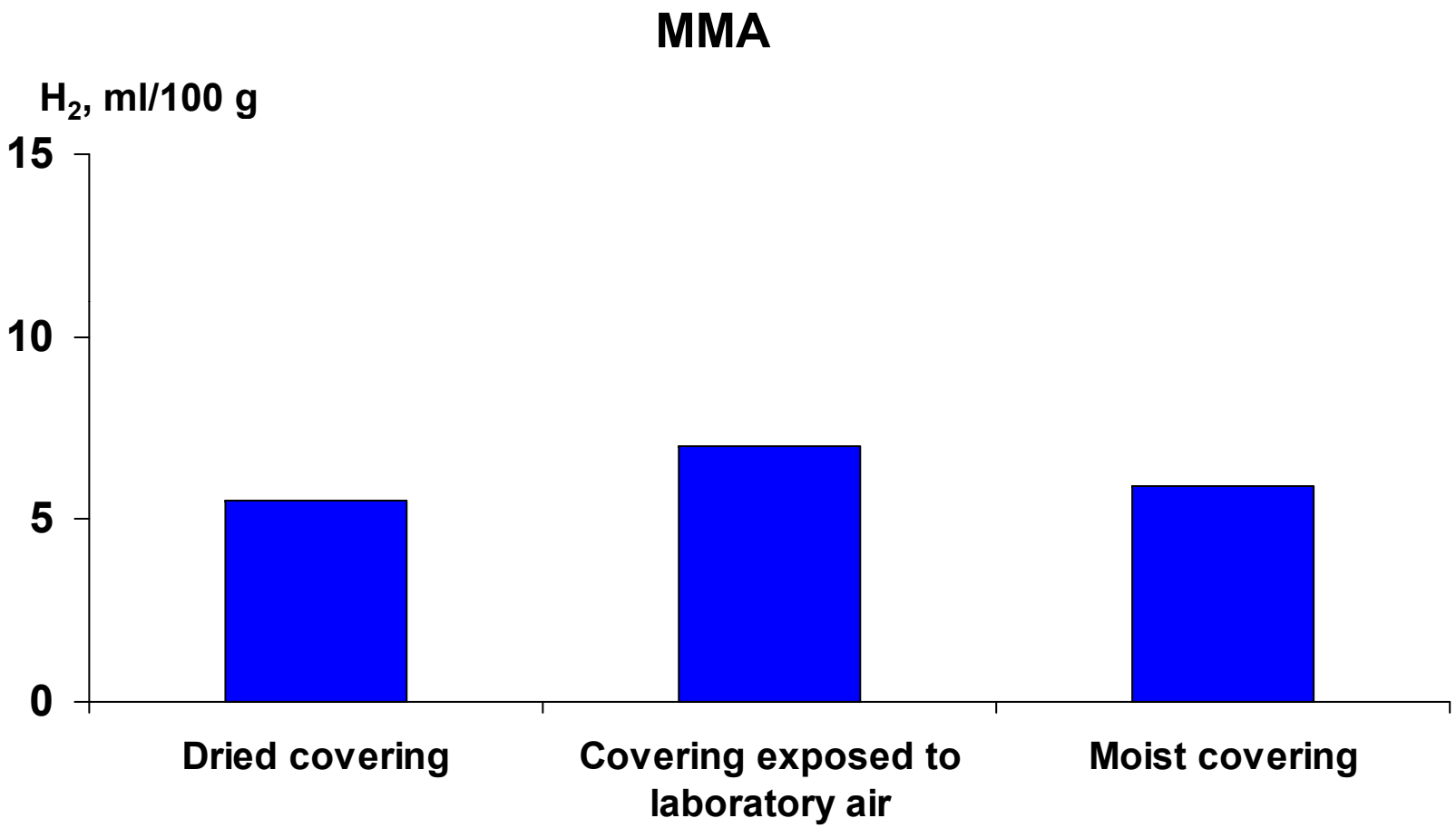
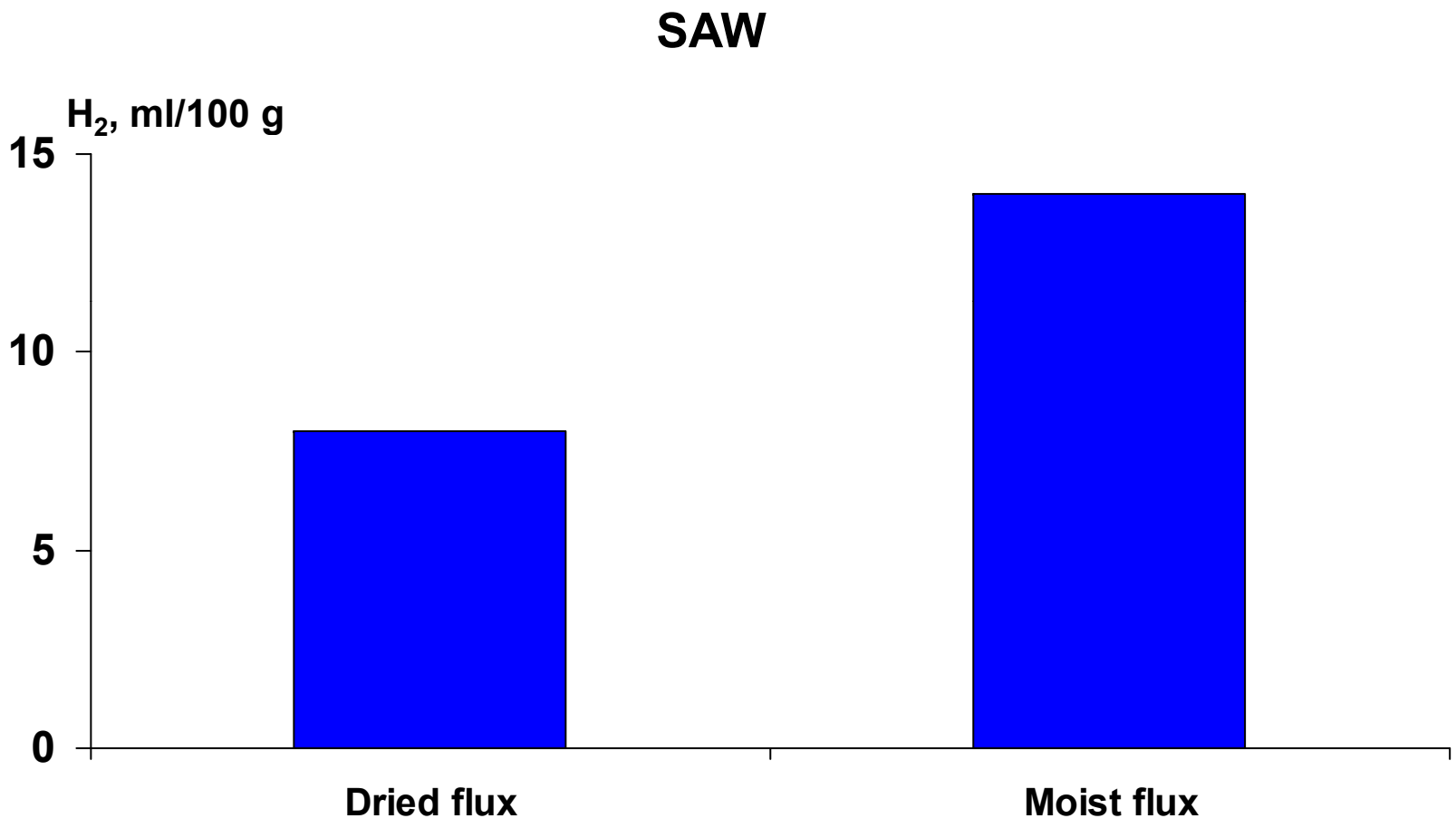
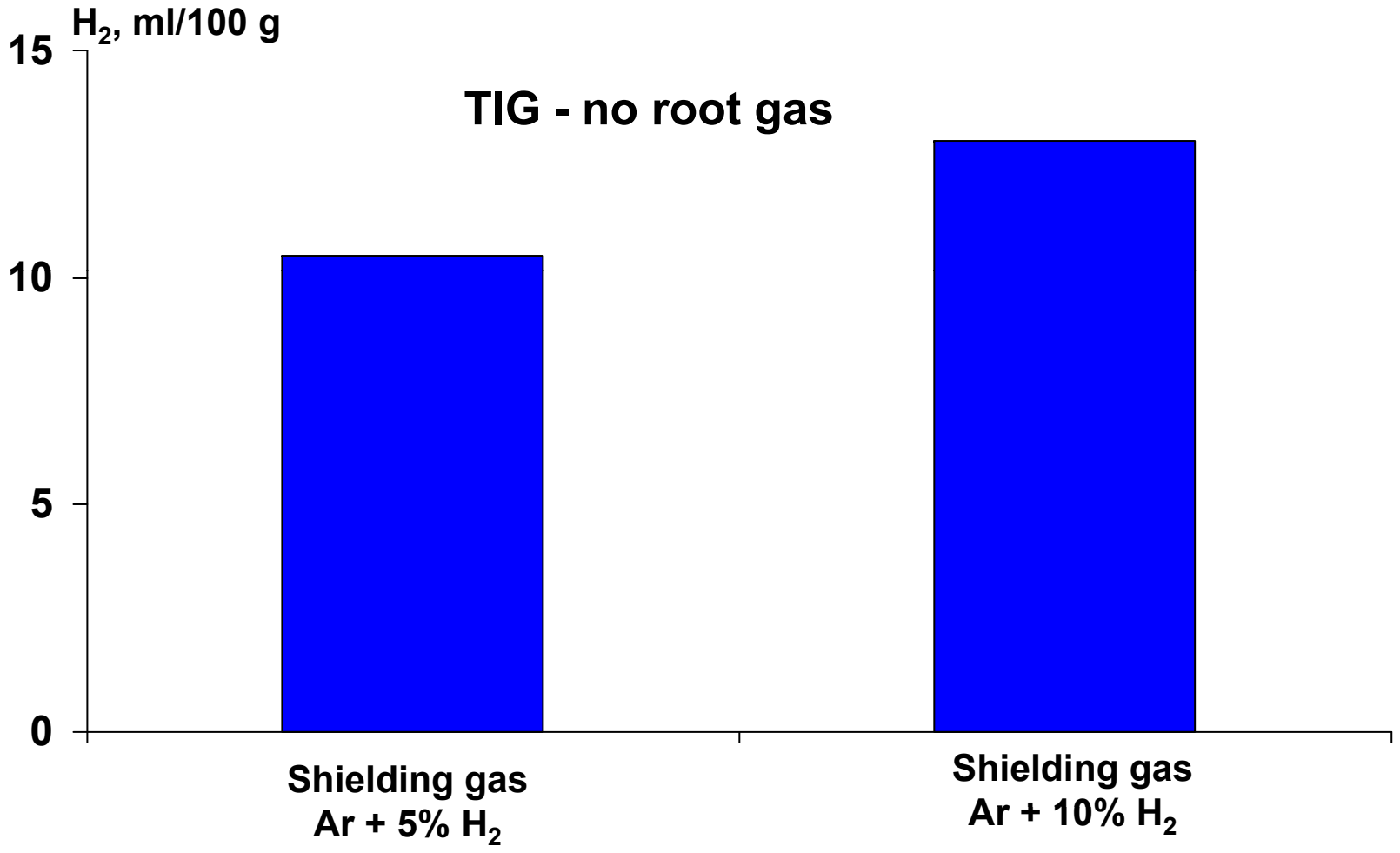
Hydrogen pick-up from covered electrodes Sandvik 25.10.4.LR



Hydrogen pick-up from SAW flux



Hydrogen pick up from shielding gas at TIG welding



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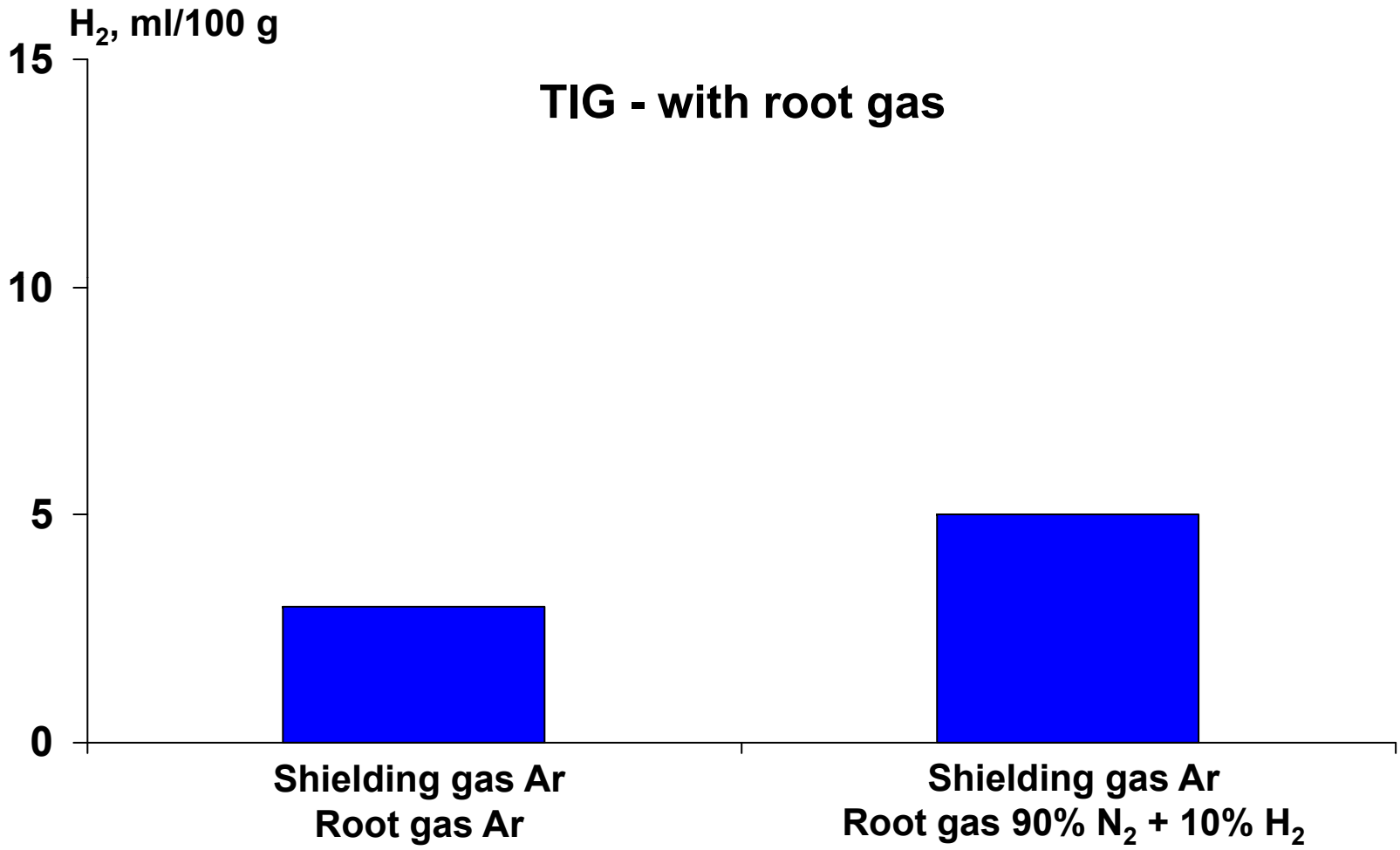
Hydrogen pick up from shielding gas and root gas at TIG welding



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Conclusions

Key Areas

- **Good Weldability**
- **Uses Conventional Welding Processes**
- **Joint Design**
- **Role of Nitrogen**
- **Heat Input Important**
- **Interpass Temperature**

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