How to weld Duplex Stainless Steel

- LDX 2101
- 2304
- 2205
- 2507

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Duplex Stainless Steel - Characteristics

Austenitic-ferritic stainless steels usually referred to as Duplex steels.

Duplex means two – 50% ferrite and 50% austenite.

Characteristics include:

- High yield strength, double that of Austenitic or Ferritic grades of S/S.
- Good ductility, easy to form with approximately 20-30% elongation.
- Good impact strength >-40°C.
- Maximum working temperature of +250°C.
- The high Cr in combination with Ni gives superior resistance to both pitting and crevice corrosion.
- Excellent weldability.

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Duplex Stainless Steel - Uses

Thanks to this exceptional combination of strength and corrosion resistance, duplex steels are widely used for:

- Heat exchanges
- Water heaters
- Pressure vessels
- Storage tanks
- Rotors, impellers and shafts
- Digesters and other equipment in pulp and paper production
- Cargo tanks in chemical tankers
- Desalination plants
- Waste gas purifiers
- Sea water systems

LDX2101, storage tank for waste water
(Courtesy of Cordwrucker)

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Duplex stainless steels – Chemical composition

Steel name	ASTM UNS	EN	Typical composition , %					
			C	N	Cr	Ni	Mo	Other
LDX 2101	S32101	1.4162	0,03	0,22	21,5	1,5	0,3	5 Mn
2304	S32304	1.4362	0,02	0,10	23,0	4,8	0,3	
2205	S31803	1.4462	0,02	0,17	22,0	5,7	3,1	
2507	S32750	1.4410	0,02	0,27	25,0	7.0	4.0	

”Lean Duplex” ⟶ LDX 2101®

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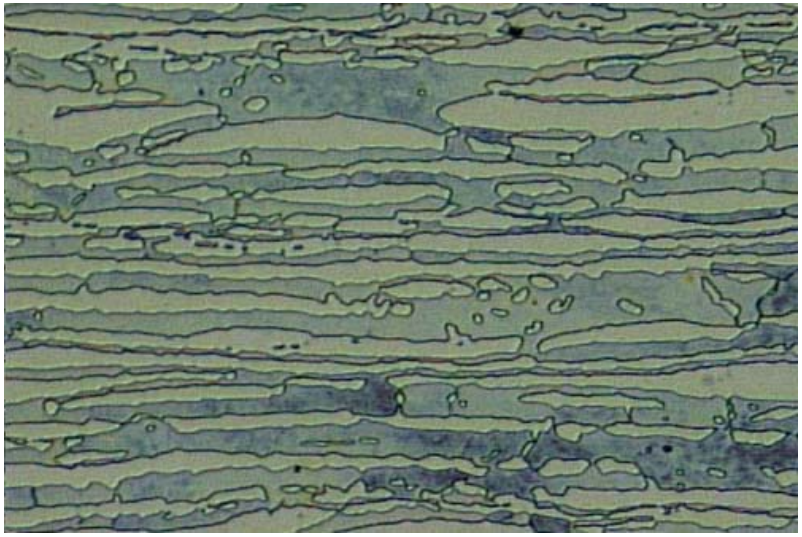
Duplex Stainless Steel - Microstructure

- After welding, cooling is often very rapid and little time for austenite to form.
- To help balance the structure filler metals are over-alloyed with nickel.
- Nitrogen is also used as a austenite stabilizing element.
- Welds between 20 to 70% ferrite are in a normal range and have good corrosion and mechanical properties.

Microstructure of Duplex 2205 Mag. X250



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Duplex Stainless Steel – Microstructure. Cont.

However, welding with:

- Wrong filler metal
- No or too little filler metal
- Narrow groove or no root gap

This can give a ferrite content over 70% risking lower ductility and reduced corrosion resistance.

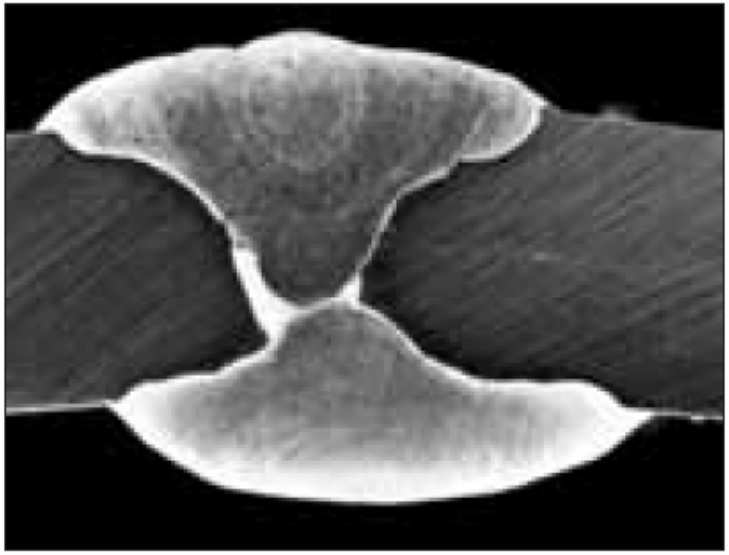

Figure 5.2. Incomplete penetration of a 2205 MIG weld

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Duplex Stainless Steel – Mechanical properties

UNS	Name	Yield	Tensile	Elongation
S30403	304L	30ksi	75ksi	40%
S31603	316L	30	75	40
S32101	2101	65	94	30
S32304	2304	58	91	25
S32205	2205	67	96	25
S32750	2507	77	106	20

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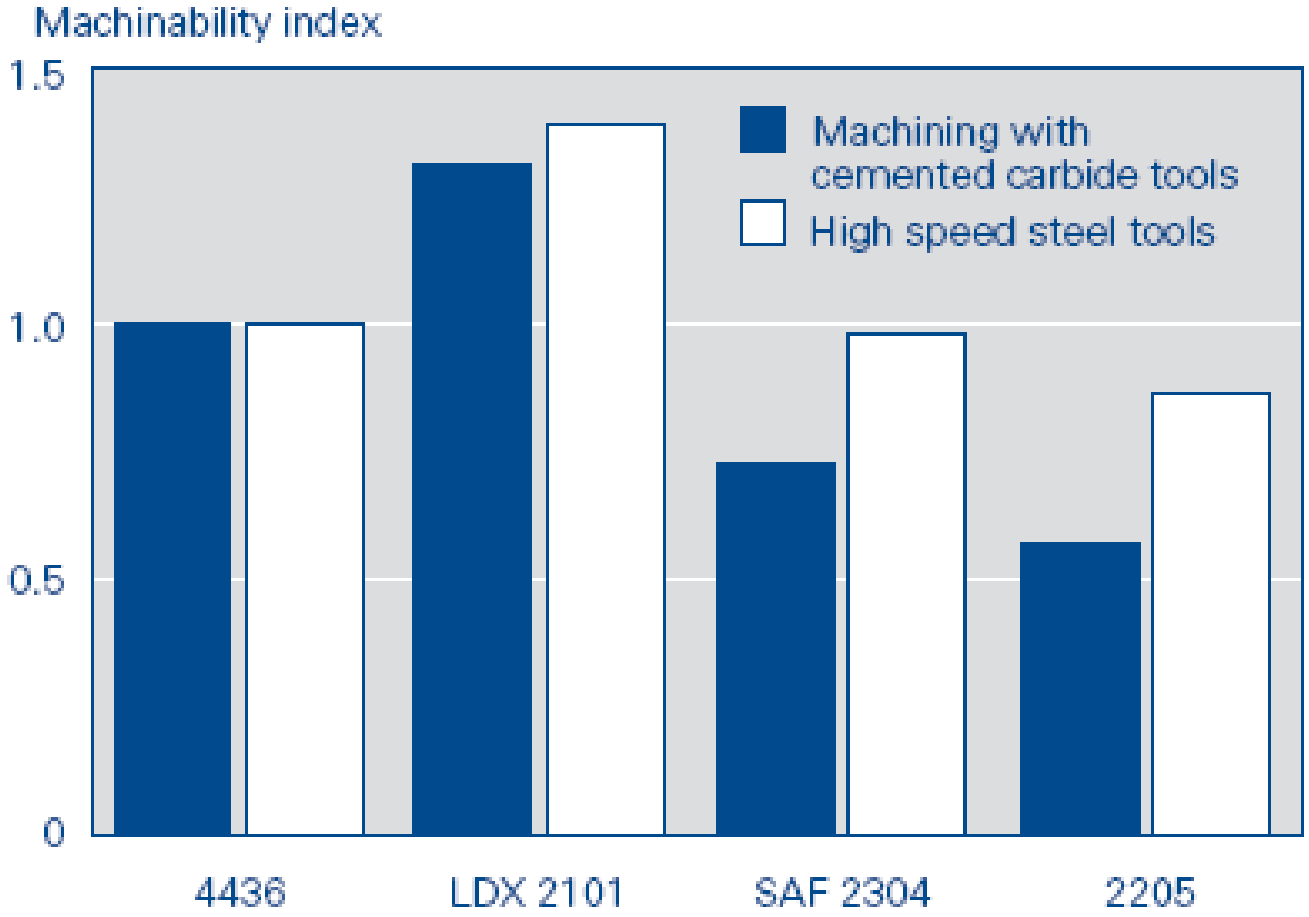
Duplex Stainless Steel – Mechanical properties



Machinability index for 4436 (316L) and Duplex material

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Duplex Stainless Steel – Mechanical properties

Fabrication

Duplex steels are suitable for most forming operations.

However due to higher mechanical strength and low toughness, operations such as deep drawing, stretch forming and spinning are more demanding to perform than with Austenitic steel.

The high strength of Duplex grades, may cause a relatively high spring back.

Segmented head Ø 12500 x 50 mm in Duplex 2205

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Duplex Stainless Steel – Mechanical properties

Cold Forming

Due to the high proof strength of Duplex material, greater working forces are required when compared to Austenitic steel.

Hot Forming

The strength of Duplex material is low at high temperatures. Hot working should be followed by quench annealing.

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Duplex Stainless Steel – Mechanical properties

Duplex steels are characterized by high strength.

High strength also means that fatigue properties are very good.

However, fatigue strength is dependent on:

- The components design shape.
- The welded joint itself.
- The welding method and joint type are also of great significance.

Example:

A TIG welded joint has better properties than one made with covered electrodes.

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Duplex Stainless Steel – Corrosion resistance

For the most part, the corrosion resistance of a welded joint is slightly lower than the parent material.

This is mainly due to:

- The temperature cycle undergone by the weld in the HAZ.
- The shape of the weld surface.
- Contaminates and defects that can be generated in welding.

To achieve the best possible corrosion resistance:

- The surface of the weld and the plate must be clean and even.
- After welding, <u>the weld metal and the HAZ must be pickled</u>

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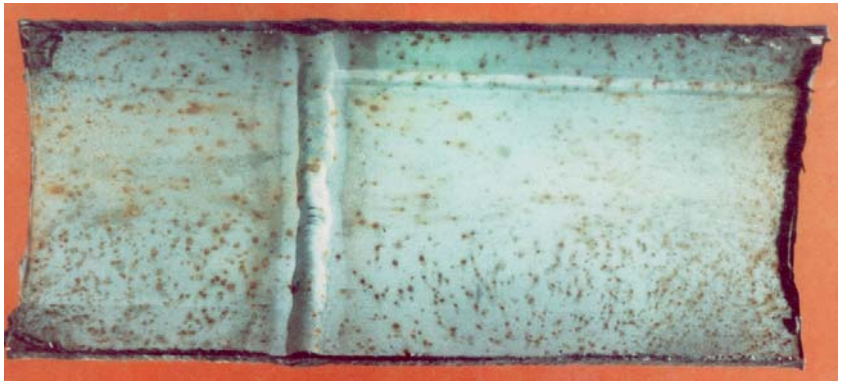
Duplex Stainless Steel – Corrosion resistance

Stress corrosion cracking caused by grinding



Pitting caused by grinding spatter

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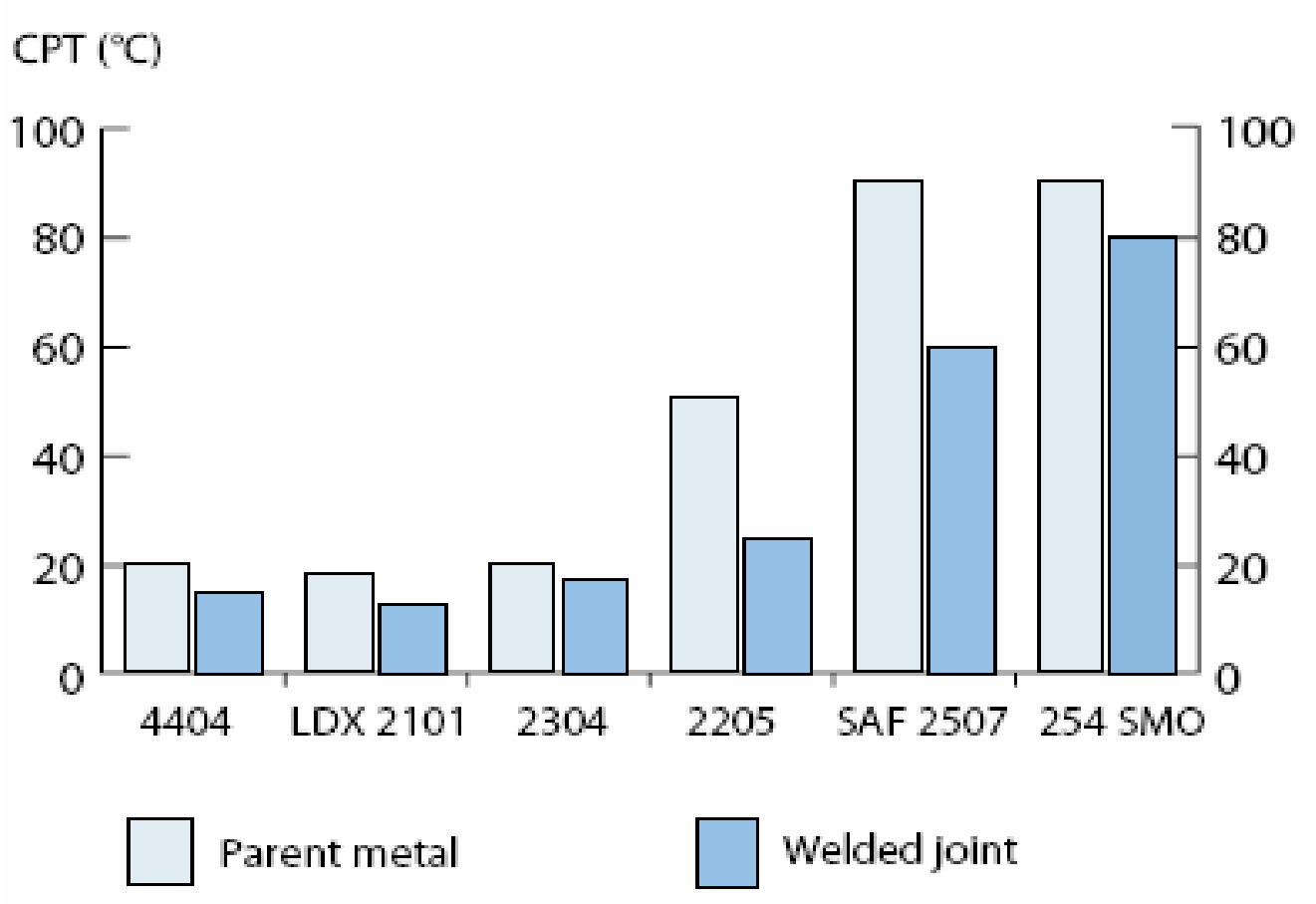
Duplex Stainless Steel – Corrosion resistance. Cont.



Typical critical pitting temperatures (CPT) as per ASTM G48 – parent metal and weld, brushed and pickled TIG joint.

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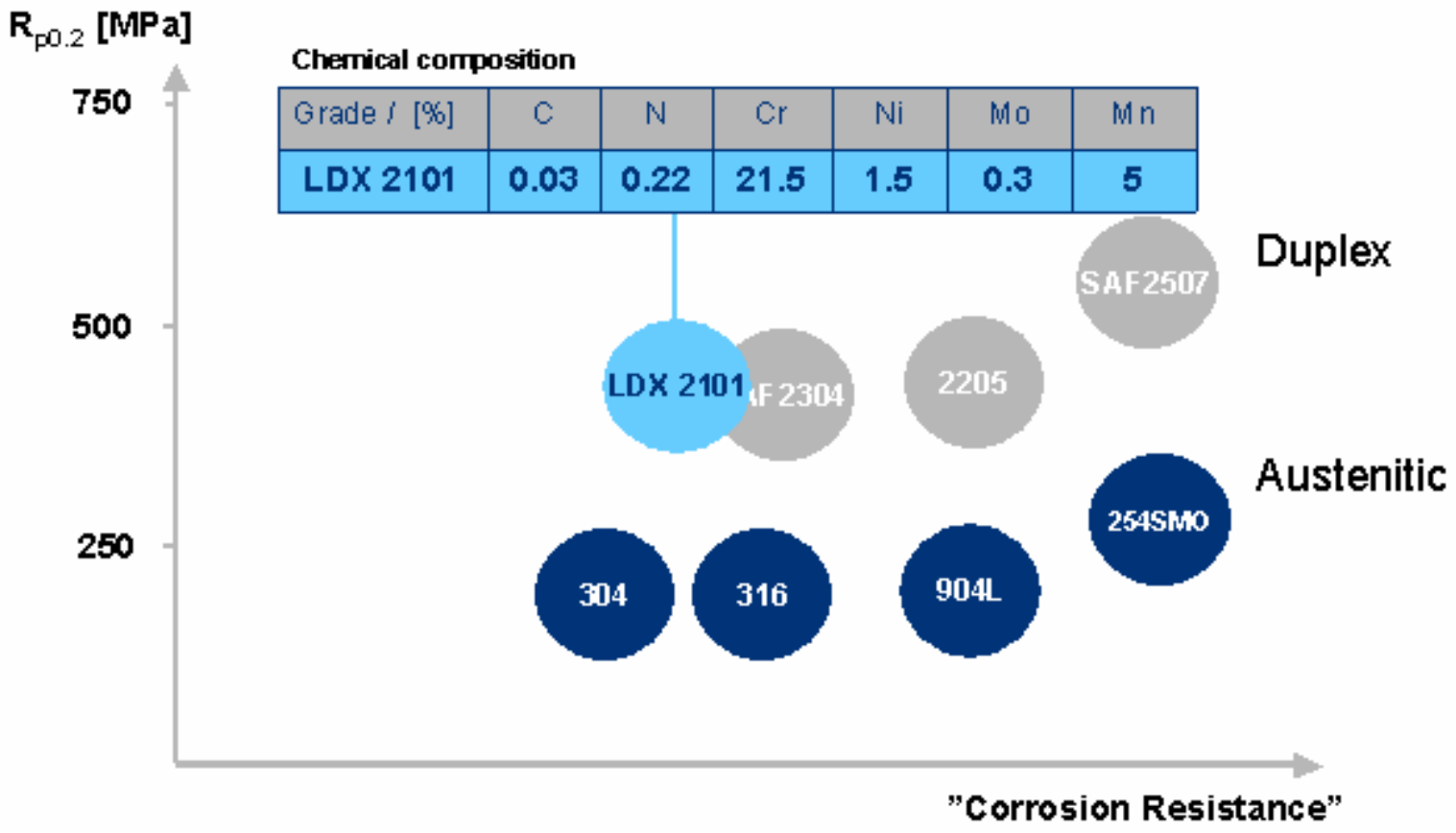
Duplex Stainless Steel – Corrosion resistance. Cont.



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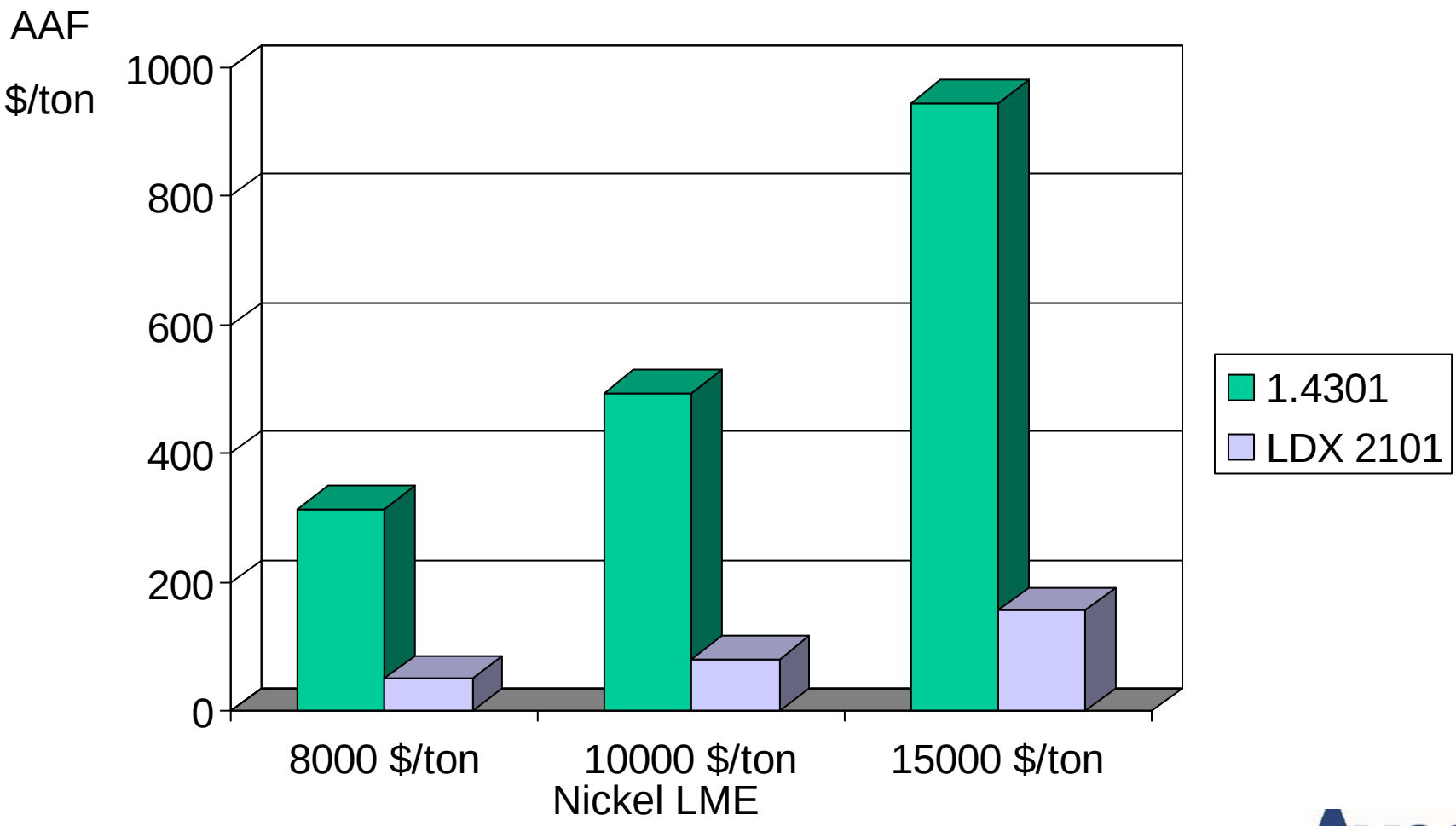
LDX 2101® - Nickel price influence on Alloy Surcharge



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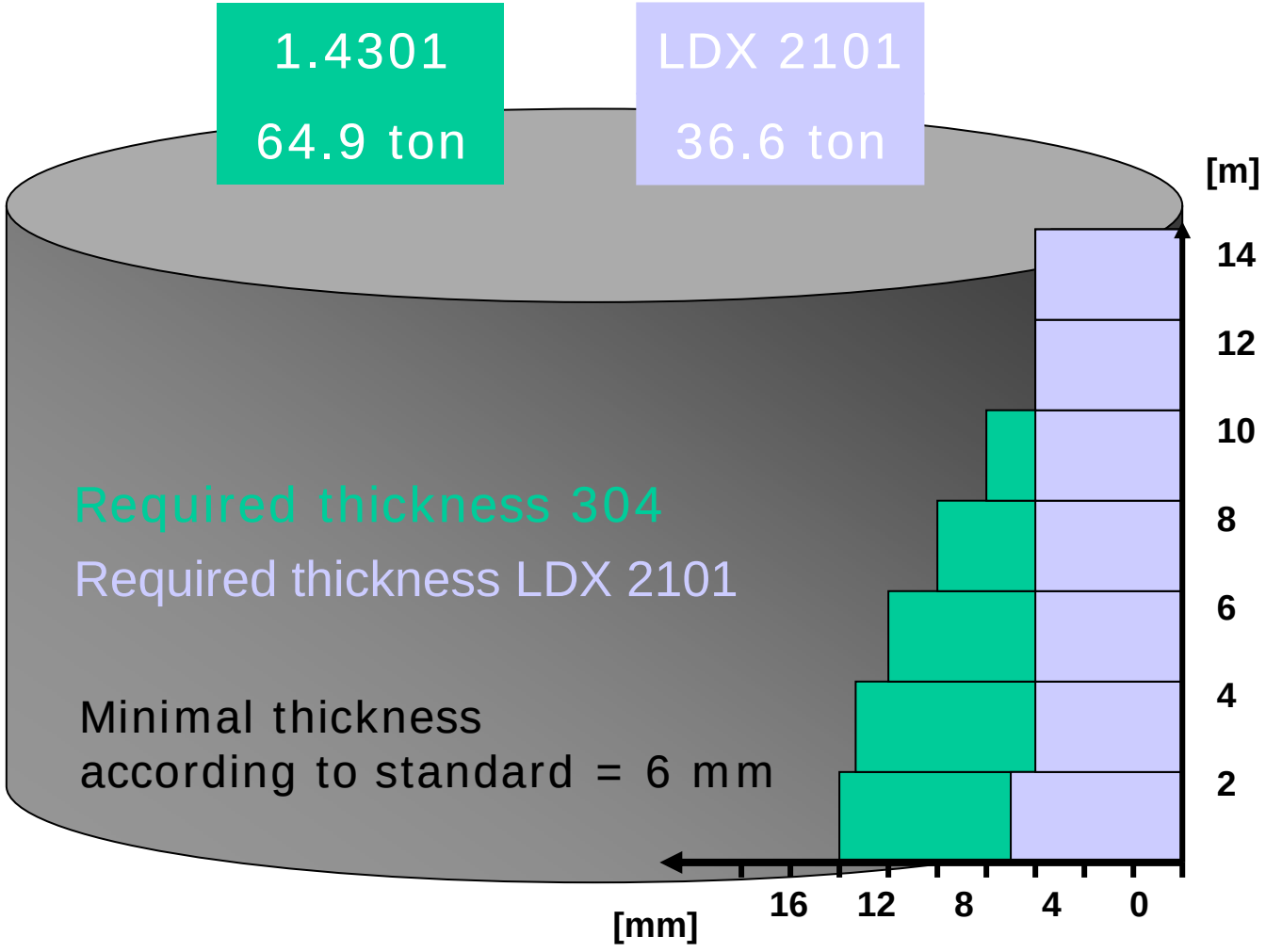
LDX 2101® - Cost advantage - Tank



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Duplex Stainless Steel – Welding methods

All conventional welding methods can be used i.e.

- MMAW, GMAW, GTAW, SAW, FCAW, PAW & LAW.

Property requirements, positional weldability and productivity usually determine the choice of welding method

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Duplex Stainless Steel – Welding methods

MMAW

•Excellent for positional welding or single sided welding where access is limited.

•DC+ gives best results.

•A short arc should be used. This gives the best stability and reduces the risk of nitrogen pick-up. The later can lead to pore formation and increase surface oxidation.

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Duplex Stainless Steel – Welding methods

GMAW

- Good for welding sheet/plate up to 6mm.
- Welding is usually from two sides but material <4mm can be welded single-side with root backing.
- Spray or pulsed current can be used.
- Advantage of spray arc is higher deposition rate.
- Advantage of pulsed arc is control and the ability to put the weld metal out of position.
- It is very important to use pulsed arc when welding super duplex SAF 2507 due to the stability of the arc.

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Duplex Stainless Steel – Welding methods

GTAW

- Normally used for thin material <4mm.
- Commonly used on pipe joints.
- Suitable for welding single–sided root beads (with or without root backing).
- Subsequent beads can then be welded using a method with higher deposition rate.

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Duplex Stainless Steel – Welding methods

SAW

- High productivity with excellent weld finish.
- Work environment considerably better than other methods.
- Disadvantage is that it is restricted to horizontal position.
- Large heat input, consequently small job present a problem.
- A basic agglomerated flux must be used.

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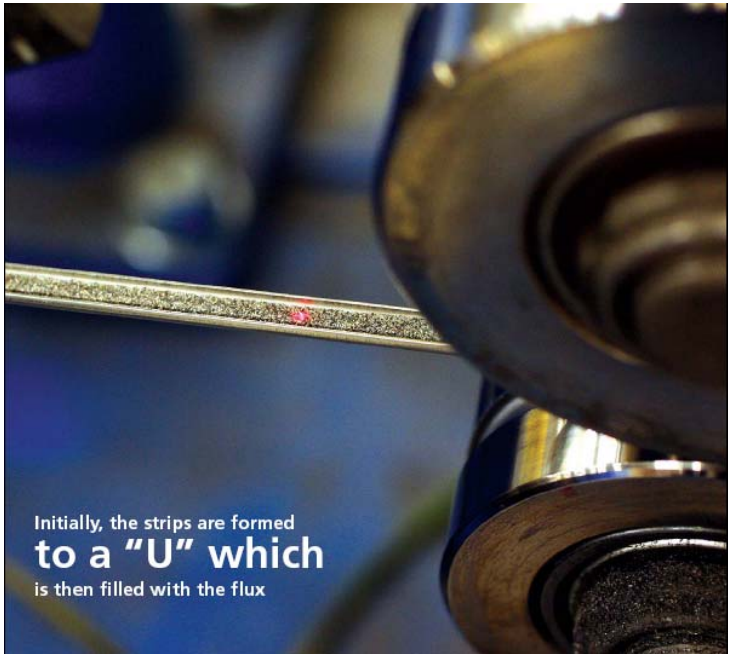
Duplex Stainless Steel – Welding methods

FCAW

- Suitable for material over 5mm.
- Single-sided welding possible using a ceramic backing.
- Fast and efficient process.
- Excellent surface appearance.



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Duplex Stainless Steel – Welding methods

Laser, laser hybrid and plasma welding

- Are all high productivity methods.
- If filler metal is not used the work piece must but heat treated.
- Penetration can be controlled.
- Low heat input.
- Zero tolerance for weld preparation.

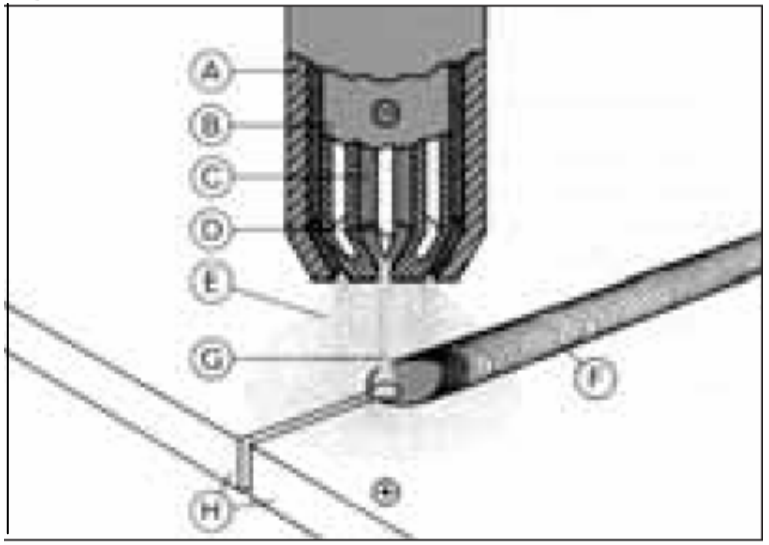

Figure 3.12. PAW

A = Insulating sheath
B = Water-cooled torch
C = Plasma gas forced into the arc
D = Tungsten electrode (non-consumable)
E = Shielding gas
F = Weld metal
G = Plasma jet
H = Parent metal

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Duplex Stainless Steel – Shielding gas selection

Shielding gases

Method	Grades	Shielding gases
MIG	LDX 2101, 2304, 2205	1. Ar+30%He+1–3%CO_2 2. Ar+1–2%O_2 or Ar+2–3%CO_2
	2507/P100	1. Ar+30%He+1–3%CO_2 2. Ar 3. Ar+30%He+1–2%N_2+1–2%CO_2
TIG	LDX 2101, 2304, 2205, 2507/P100	1. Ar+2%N_2 +10–30%He 2. Ar
FCAW	LDX 2101, 2304, 2205	1. Ar+16–25%CO_2 2. 100% CO_2
Plasma	LDX 2101, 2304, 2205, 2507/P100	1. Ar* 2. Ar+20–30%He+1–2%N_2*
Laser	LDX 2101, 2304, 2205, 2507/P100	1. Ar

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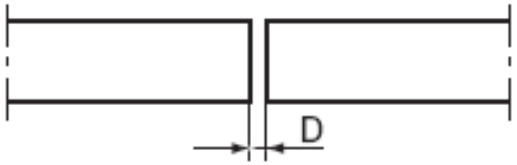
Duplex Stainless Steel – Weld joint preparation

Joint type 1
I-joint, t < 2.5 mm
D = 1.0–2.0 mm
Single-sided, with or without root backing

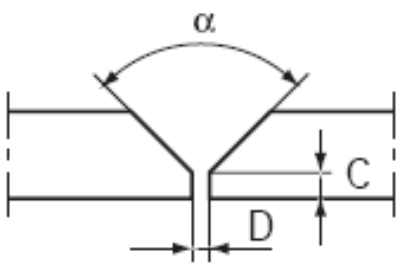
I-joint, t < 4.0 mm
D = 2.0–2.5 mm
Double-sided without root backing but with root grinding



1. I-joint for: single-sided MMA, TIG and PAW; and, double-sided welding using the same methods plus MIG and FCAW. Suitable root protection must be used with single-sided TIG and plasma welding.

Joint type 2
V-joint, t = 4–16 mm
α = 60°–70°
C = 0.5–1.5 mm
D = 2.0–4.0 mm (4–6 mm against abacking)
Single-sided, with or without root backing

V-joint, t = 4–16 mm
α = 60°–70°
C = 2.0–2.5 mm
D = 2.5–3.5 mm
Double-sided without root backing but with root grinding



2. V-joint (t > 4 mm) for: single and double-sided MMA and TIG welding as well as double-sided MIG and FCAW. Single-sided welding is also possible with FCAW, but a ceramic backing must then be used.

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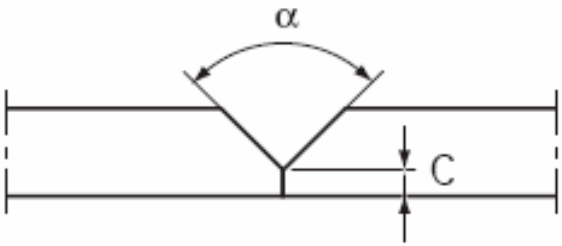
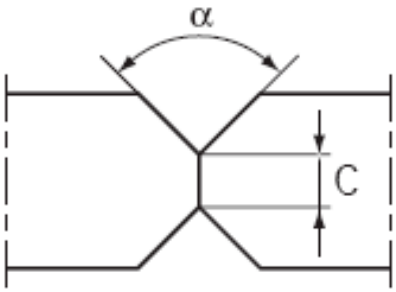
Duplex Stainless Steel – Weld joint preparation

Joint type 3
V-joint, t = 8–16 mm
α = 80°–90°
C = 3–6 mm
Double-sided welding without root gap, but with root grinding



3. V-joint for SAW. So that full penetration is possible, the root bead must be ground precisely.

Joint type 4
X-joint, t = 14–30 mm
α = 80°–90°
C = 3–8 mm (2507/2101 3–4 mm)
Double-sided welding without root gap, but with root grinding



4. In SAW, an X-joint is to be recommended where plate thickness exceeds 16 mm. To achieve best penetration when welding 2205 and 2304, the straight edge can be increased up to 8 mm. The torch must then be slightly angled (around 15°) in the direction of welding. In this way, thicknesses up to 20 mm can be welded with only two beads. However, for LDX 2101 and SAF 2507, the straight edge should not exceed 4 mm.

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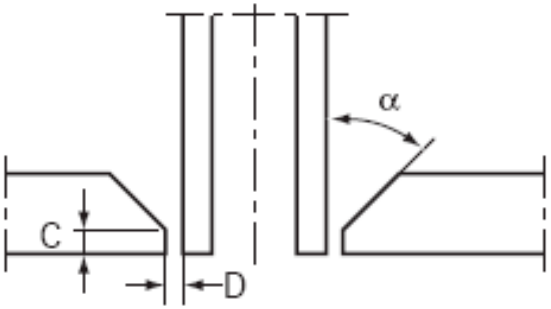
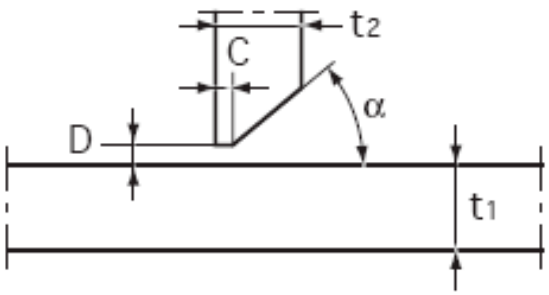
Duplex Stainless Steel – Weld joint preparation

Joint type 5
V-joint, t = 4–16 mm
α = 50°
C = 1.0–2.0 mm
D = 2.0–3.0 mm
Single-sided without root backing



5. Edge preparation for pipe joints. Welding is most suitably performed using TIG or MMA for the root bead. For in creased productivity, FCAW may then be used.

Joint type 6
Half V-joint, t = 14–30mm
α = 50°
C = 1.5–2.5 mm
D = 2.0–3.0 mm (4–6 mm against a backing)
Single-sided, with or without root backing



6. Half V-joint with full burn-through. Where grinding the root presents difficulties, the root should be welded as a single-sided TIG or MMA weld or, alternatively, as FCAW against a ceramic backing. In this type of joint, the distance between tacks should not exceed 150 mm. This is so that shrinkage does not prevent full burn-through.

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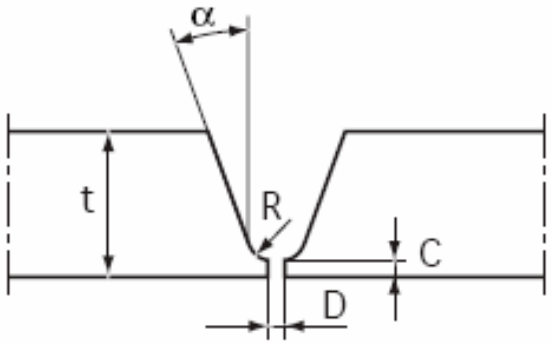
Duplex Stainless Steel – Weld joint preparation

Joint type 7
U-joint, t > 20 mm
α = 10°
R = 8 mm
C = 2.0–2.5 mm
D = 2.0–2.5 mm (4–6 mm against a backing)
Double-sided without root backing but with root grinding



7. Simple U-joint for the welding of thick sections (t > 30 mm). The joint can advantageously be made as a symmetrical or asymmetrical double U-joint. Root welding is most suitably carried out as a TIG or MMA weld followed by, for example, FCAW or SAW.

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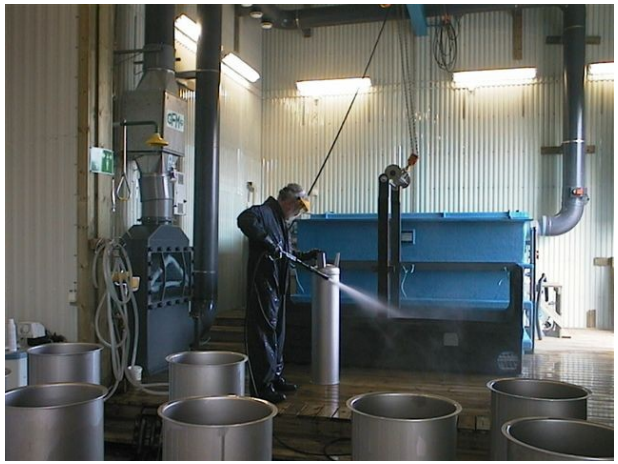
Duplex Stainless Steel – Pre-weld cleaning

To ensure good weldability and reduce the need for post-weld cleaning

- All joint surfaces, and surfaces adjoining these must be thoroughly cleaned before welding.
- Dirt, oil and grease must be removed by using a cleaning agent such as Avesta Cleaner 401.
- All rough edges must be completely removed by gentle grinding.
- Oxides, paints and primers must be entirely removed from the joint and 50mm away from joint edge.



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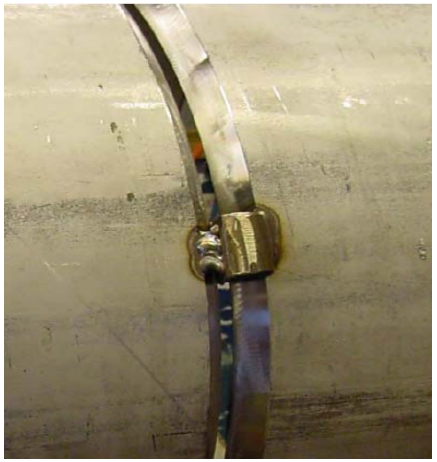
Duplex Stainless Steel – Tack welding

To prevent shrinkage during welding precise tacking is important.

- For material up to 6mm tack length should be 10-15mm.
- Above 6mm tack length should be 20-25mm.
- Distance between tacks is 150-200mm.
- In single sided welding, the entire tack must be ground away before welding.
- In double sided welding it is sufficient to grind away the beginning and the end of the tack.



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Duplex Stainless Steel – Starts and stops

Striking and extinguishing the arc

- Important to use the correct technique when striking and extinguishing the arc.
- In regards to the metallurgical, mechanical and corrosion properties, each start and stop is critical.
- Avoid arc scars always strike arc in joint.
- If scars occur they must be carefully repaired by grinding and polishing or in worst case, repair welding.
- All crater cracks and slag inclusions must be removed.

Grinding scars

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Duplex Stainless Steel – Planning the weld sequence

Root beads

- To ensure correct metallurgy and structure of the final weld, the root gap must be sufficient to allow the correct quantity of filler metal.
- Must have the correct geometry i.e. no concavity, undercutting or lack of fusion.
- Best possible productive welding method.

Single sided TIG root bead

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Duplex Stainless Steel – Planning the weld sequence

Filler beads

- Must be deposited with the highest possible productivity.
- Generally speaking, welding is carried out with the highest possible heat input that is consistent in maintaining properties and weldability.
- Visual inspection between passes.
- Slag residues and welding oxides removed before depositing next layer.

Some welding process combinations:

- *TIG root pass + MMA, MIG, or SAW fill passes*
- *MMA root pass + SAW or FCAW fill passes*

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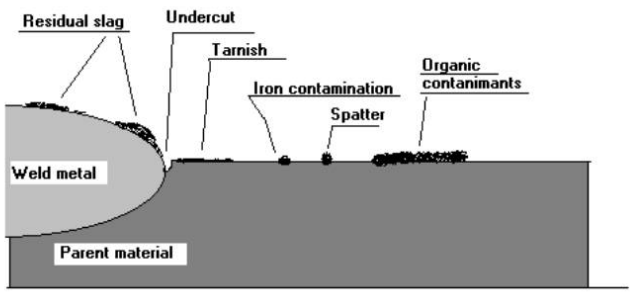
Duplex Stainless Steel – Planning the weld sequence

The cap bead

- Primarily intended to give the weld good corrosion resistance and some structural integrity.
- Undercut, unevenness, excessive reinforcement, gaps, etc all have a negative impact on corrosion resistance.
- Aesthetic considerations are often also important.



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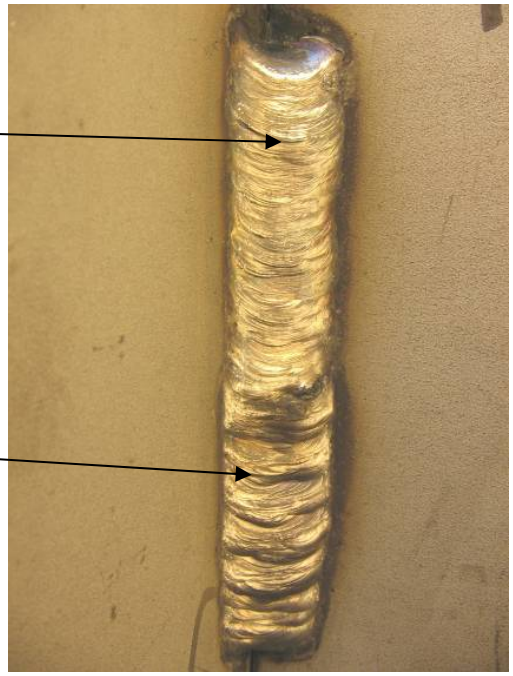
Duplex Stainless Steel – Welding techniques

- In the flat position there should be no weaving.
- Vertical up position weaving of up to 20mm is advantageous.
- For Sub-Arc a 10-15° forehand welding direction increases penetration. This allows the root face edge to be welded up to 8mm.

Avesta 3D Electrodes

Competitor



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Duplex Stainless Steel – Distortion and preheating

Distortion

- Coefficient of expansion is lower than austenitic steels.
- It is slightly higher than carbon steels.
- However, this does not mean that tack welding can be simplified.

Preheating

- On a whole, S/S do not require preheat.
- Welding takes place at room temperature
- At low temperatures a maximum of 50°C preheat is advisable to drive off any moisture.

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Duplex Stainless Steel – Interpass temperature

- LDX 2101 is 150°C
- 2304 and 2205 welded below 200°C
- SAF 2507 is far more sensitive and should not be welded above 100°C.
- Thermal conductivity is same as austenitic and lower than carbon steel. This means it takes longer to reach the correct interpass temperature.
- Interpass temperature must be measured.
- Avoid thermal cryons.

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Duplex Stainless Steel – Heat input

General recommendations

- 2304 max. 2.0kJ/mm
- 2205 max. 2.5kJ/mm
- LDX 2101, SAF 2507 max. 1.5kJ/mm

Duplex should not be welded with too low a heat input.

Could cause high cooling rates resulting in ferrite above 70%

Minimum heat input is 0.5kJ/mm

U = voltage
I = current
V = speed mm/s

$$\text{Heat input} = \frac{U \times I}{V \times 1{,}000}$$

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Duplex Stainless Steel – Post weld treatment

- Clean prior to pickling to remove contaminates with Avesta cleaner 401.
- Pickle for 1 hour with RedOne pickling paste.
- Rinse methodically.

Avesta RedOne™ Pickling Spray 240 – spray pickling with Best Available Technique.

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Conclusions

BEFORE WELDING

- A slightly wider root gap and joint angle than for standard stainless steel.
- Thoroughly clean joint.
- Only stainless brushes should be used.
- Preheating is normally not recommended.
- Joint preparation by Plasma cutting should be followed by grinding to remove oxide layer.
- Electrodes and Sub Arc Flux should be re-baked before welding.

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Conclusions

DURING WELDING

- Use the right heat input.
- Avoid striking the arc outside the joint.
- Use the correct root gas.
- Keep welding Gun 90º to joint
- Do not draw a long arc when welding
- Avoid excessive weaving.
- Heat input from 0.5-2.5kJ/mm
- Interpass temperature 100-200ºC
- Avoid rapid cooling and low heat inputs.
- Tig is strongly recommended for root passes in one-sided welds.
- Welding against copper-backing should be avoided because of the risk of too rapid cooling.

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Conclusions

AFTER WELDING

- Thorough cleaning of all slag and oxide on and around the weld must be removed.
- Brushing should be done manually because of the risk of micro-crevices.
- Post weld heat treatment is not normally needed.
- Pickling recommended.

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Avesta Welding consumable range

Full range of consumables for welding stainless steel and nickel base alloys

- Covered electrodes
- MIG wire
- TIG wire
- Sub arc wire and flux
- Flux cored wire

Martensitic, austenitic, austenitic-ferritic (duplex), fully austenitic and heat resistant steels and dissimilar welding between stainless and mild steel or nickel base alloys.

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Avesta Finishing Chemical range

- Paste / Gel
- Solution
- Bath
- Cleaning
- Neutralising
- Passivating
- Accessories

All pickling products conform to international standards:
ASTM A-380, BSI CP-3012, KWU RE-AVS 8, RCCM F-5000-6000

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www.avestawelding.com

Our web - site contains a lot of interesting and useful information about welding and pickling of stainless steel.

You are welcome to visit us on

www.avestwelding.com

www.avestafinishing.com

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