Duplex Stainless Steel Fabrication

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- **Promoting** molybdenum - as a material with superior properties and performance in a wide variety of metallurgical, chemical and other product applications

- **Expanding** the applications in which molybdenum is used via:
  - Market development programs
  - Co-operation with consumers, end-users and allied organizations
  - Technical brochures and training seminars to explain the advantages of using molybdenum-containing products in various industries

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Presentation Overview

- What is Duplex Stainless Steel?
- Chemical Composition
- Mechanical Properties
- Cutting
- Forming
- Machining
- Welding
- Post-Fabrication Cleaning

Types of Stainless Steels

Austenitic	**Type 316**
Ferritic	**Type 430**
Duplex	**Type 2205**

Chemical Composition

Type	%Cr	%Ni	%Mo
316 (austenitic)	17	10	2
430 (ferritic)	16		
2205 (duplex)	22	5	3

ASTM Mechanical Properties
(Minimum Limits)

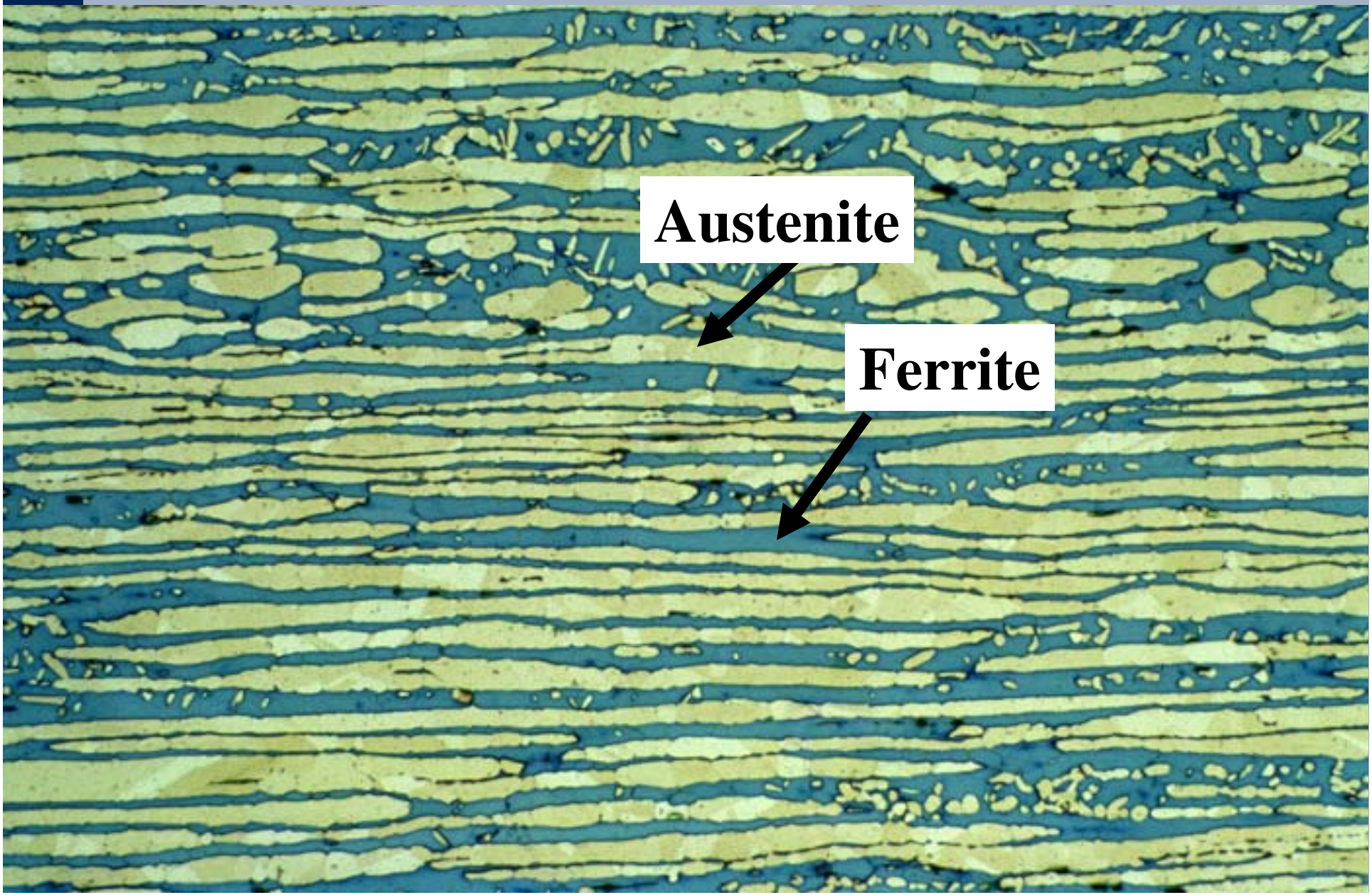
Type	Yield (ksi)	Tensile (ksi)	Elong. (%)
304L	25	70	40
316L	25	70	40
2205	65	95	25

What is Duplex Stainless Steel?

Duplex Stainless Steels Consist of Austenite and Ferrite

Duplex Microstructure

Courtesy of Outokumpu



Duplex Stainless Steel Types

Lean	2304	23% Cr, 4% Ni
	LDX 2101	21% Cr, 1% Ni
	2202	22% Cr, 2% Ni
	2102	21% Cr, 2% Ni
Standard	2205	22% Cr, 5% Ni
Super	2507	25% Cr, 7% Ni

Advantages of Duplex

- Strong
- Stress corrosion cracking resistant
- Pitting / crevice corrosion resistant
- Erosion resistant
- Fatigue resistant
- Cost effective (lower nickel contents)

Cutting Stainless Steel

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Cutting Duplex Stainless Steel

- Mechanical
  - Sawing
  - Shearing
  - Abrasive wheel cutting
  - Water-jet cutting
- Thermal
  - Plasma cutting
  - Laser cutting

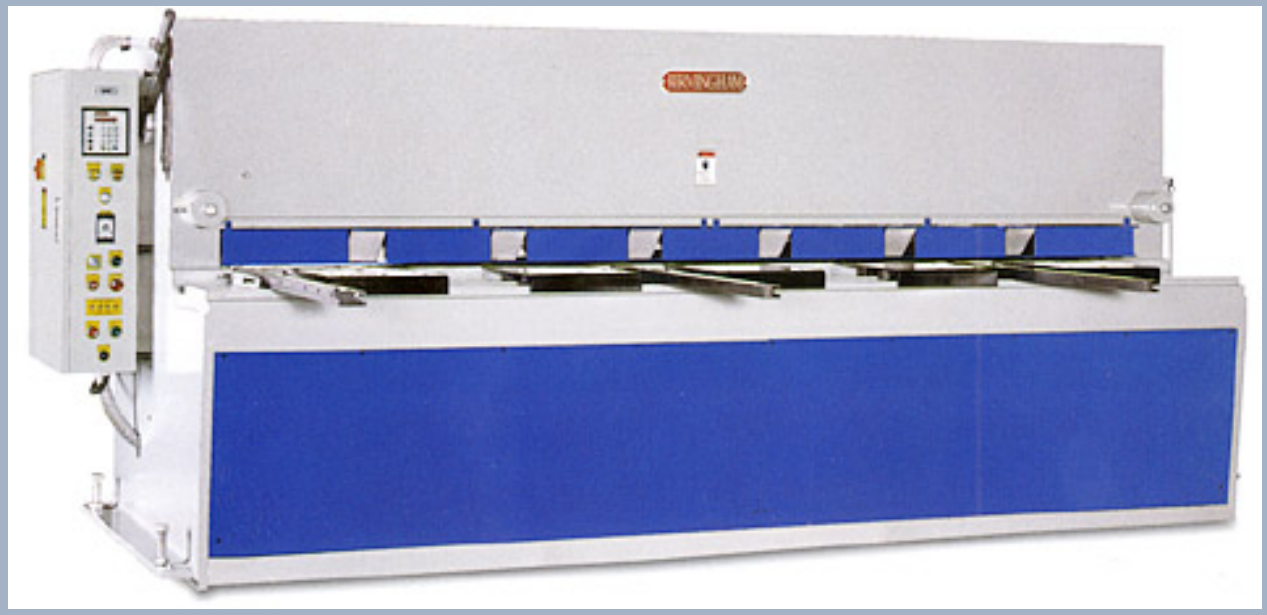
Cutting: Sawing

- Similar to austenitic stainless steel
- Powerful machine
- Proper blade alignment
- Coarse toothed blade
- Slow to moderate cutting speed
- Heavy feed
- Generous flow of coolant

Cutting, Mechanical Shearing

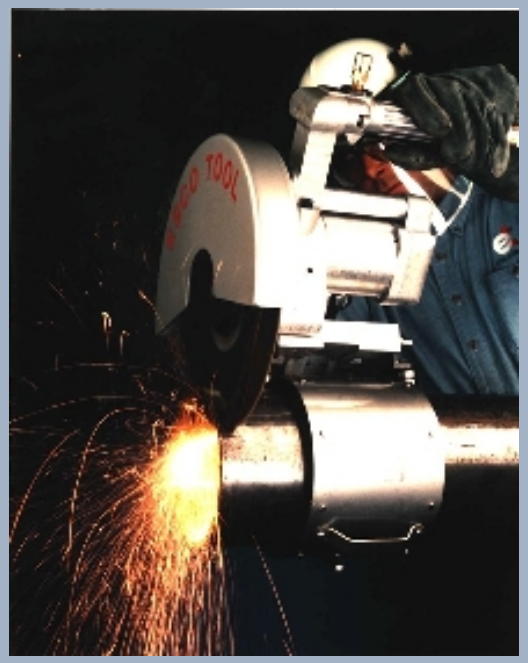
- More force and heavier equipment will be required to shear stainless steel compared to carbon steel
- Carbon steel - 1/2” thick shear limit
- Austenitic stainless steel - 1/4” max.
- Duplex stainless steel - 3/16” max.

Mechanical Shearing



- A general clearance guide is to use a clearance of 5% of the metal thickness between shear knives
- To counter the shearing force required for duplex stainless steel, the hold down pressure on the clamps may have to be increased
- BLADES MUST BE SHARP!

Abrasive Cutting



- Abrasive wheels, rotating at high speed can be used for straight line cutting of sheet and thin gauge plate and for cut-off operations on relative small sections
- Thick section cut-off operations are usually done wet
- Use uncontaminated vitrified or resin-bonded wheels
- DO NOT INDUCE OVER-HEATING

Cutting: Plasma and Laser

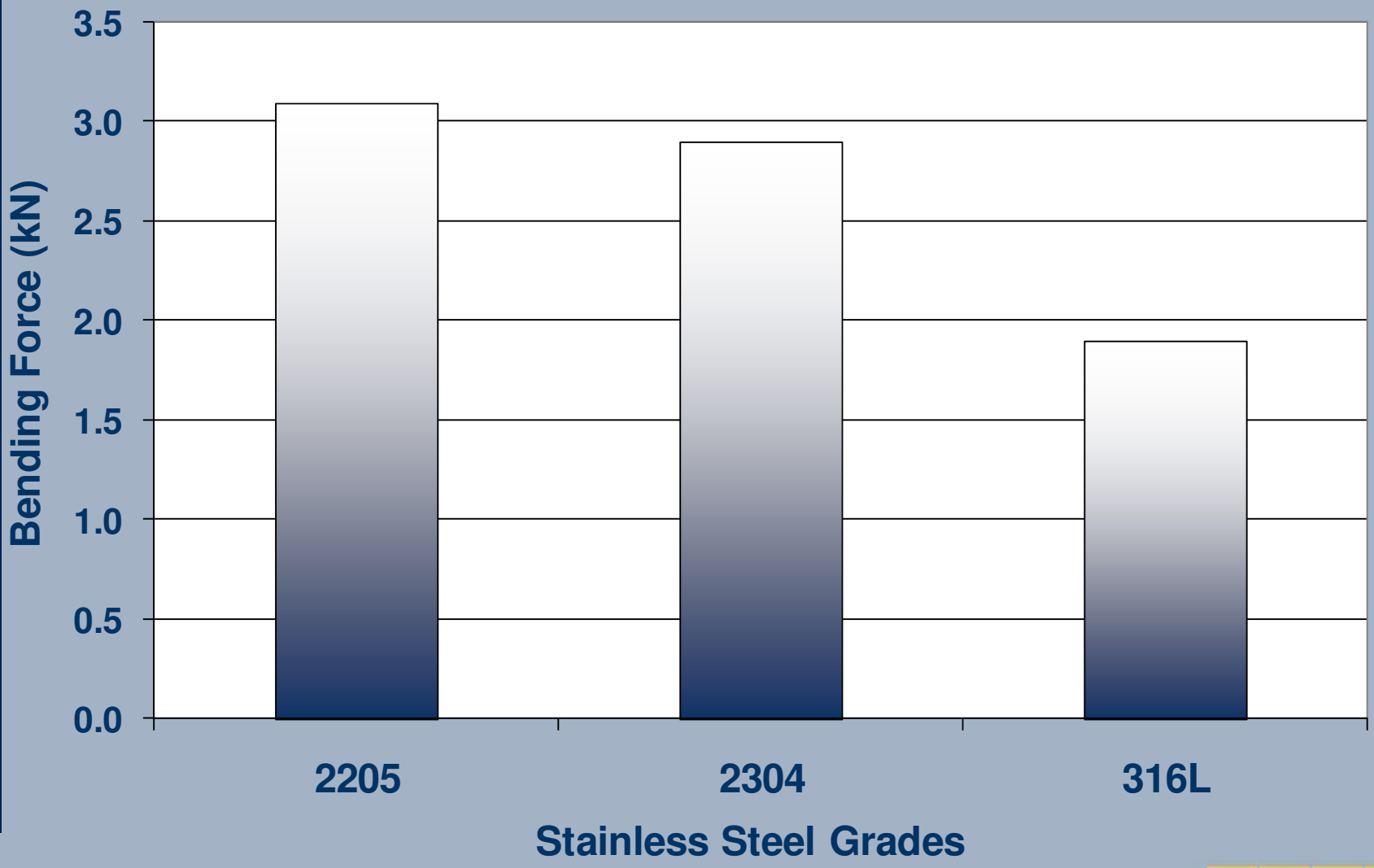
- Same equipment as for 304/316
- Optimum parameters vary slightly

Bending - Springback

- Duplex stainless steels, with their higher strength and higher rate of work hardening, require more power to bend than carbon steel

- Duplex stainless steel must be bent further than carbon steel to result in the same angle since there is more springback

Minimum Bending Force



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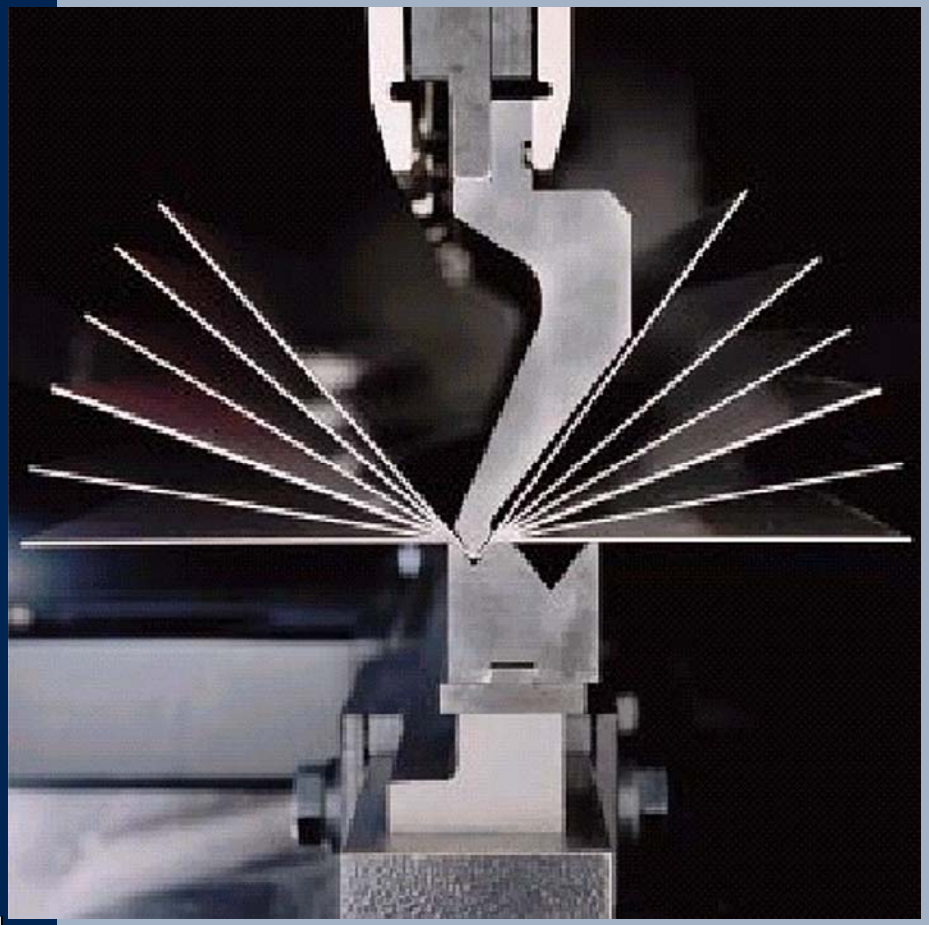
Forming Stainless Steels



- Duplex stainless steels have high work hardening rates - the strength increases as they are formed
- Greater springback than carbon steels
- Avoid contamination from tooling: Use dedicated tooling, or provide surface protection

Avoid Iron Contamination!

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Avoid Contamination from Tooling During Forming

- Ensure particles such as carbon steel or rust are not pressed into the surface
- Adopt some combination of the following guidelines:
  - Use dedicated tooling
  - Clean all contamination from the surface of tooling before use
  - Do not use carbon steel tooling - use tool steel or stainless steel or hard chrome plated tooling
  - Protect the surface of the stainless steel

Cold Forming

- Duplex ductility lower than austenitic
  - avoid sharp bend angle
  - bend radius at least twice the thickness
- Duplex much stronger than austenitic
  - higher forces necessary
  - more spring-back
- Duplex cold works readily
  - Requires more annealing stages than austenitic

Hot Forming

- Avoid critical temperature range for sigma phase (1300 - 1800˚F)
- Duplex is very soft between 1750 and 2100°F
  - easy to hot form

Hot Forming Temperature Range

Grade	Hot Forming Temperature Range	
	°C	°F
2205	1100 to 950	2010 to 1740
25 Cr Duplex	1150 to 980	2100 to 1795
2507	1200 to 1025	2190 to 1875
Types 304/316	1205 to 925	2200 to 1700

Hot Forming

- Lower temperature can cause cracking
- Higher temperature can cause tearing
- Full solution annealing after hot forming

Minimum Annealing Temperature

Grade	Minimum Annealing Temperature	
	°C	°F
2205	1040	1900
25 Cr Duplex	1040	1900
Superduplex (depending on grade)	1025 to 1100	1875 to 2010

Machining

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Machining Duplex

- High work hardening
- Low thermal conductivity
- High toughness
- “sticky”
- Poor chip breaking

General Rules for Machining

- Good edge sharpness
- Cutting tool with high edge strength
- Sufficient cutting depths
- Frequent insert replacement

Comparison
Austenitic - Duplex

Alloy content ↑ ⇒ machinability ↓

- Duplex: harder
- Duplex: faster strain hardening
- Higher tool wear
- Lower machinability

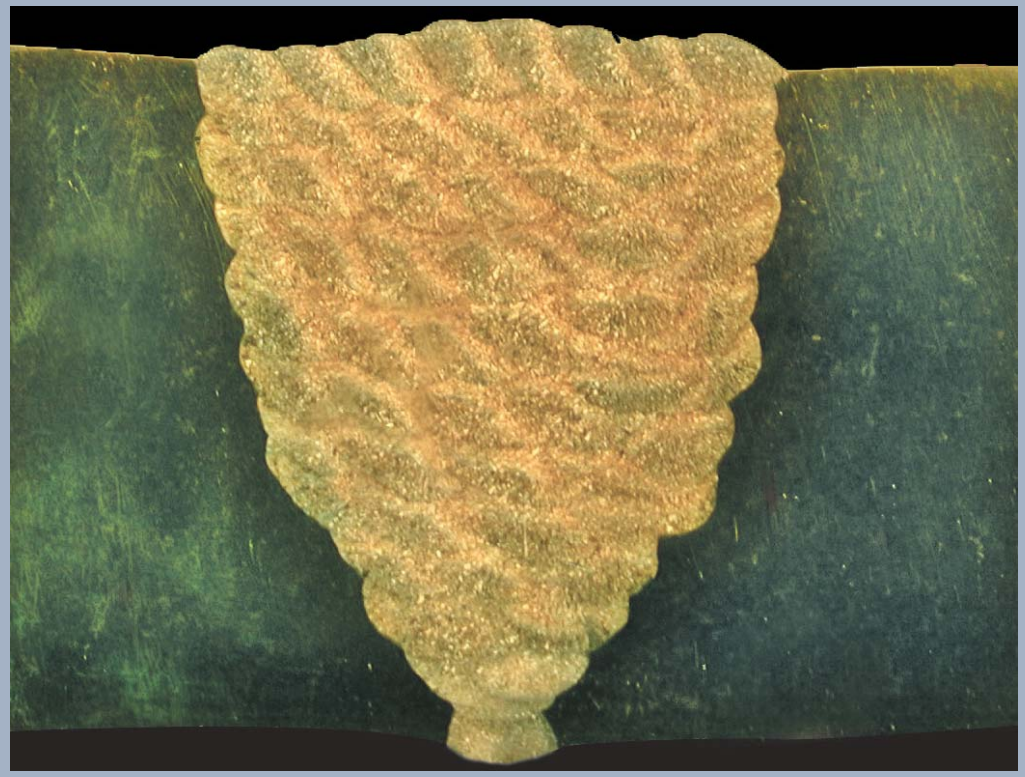
Face Milling with Cemented Carbides

Stainless Steel or machining data	Roughing		Finishing	
	Speed (m/min)	Speed (sfm)	Speed (m/min)	Speed (sfm)
Lean duplex (2304)	100-130	330-425	130-150	425-525
2205	50-80	165-260	80-110	260-360
Superduplex	30-50	100-165	50-70	165-230
Feed (per tooth)	0.2-0.4 mm	0.008-0.075 in.	0.1-0.2 mm	0.004-0.008 in.
Depth of cut	2-5 mm	0.080-0.200 in.	1-2 mm	0.040-0.080 in.
Carbide Grade	2304, 2205: ISO P20-P40 Superduplex: ISO P25-P40		2304, 2204: ISO P10-P25 Superduplex: P20-P30	

Summary

- Machinability generally lower than standard austenitic grades (300-series)
- Higher forces necessary for machining and forming
- Adjust parameters to optimize

Duplex Stainless Steel Welding



Similarities: Austenitic vs. Duplex

- **Same pre-weld joint cleaning**
  - Remove all debris, dirt, paint and oil
  - Remove water or moisture
- **Same joint preparation**
  - Remove heavy oxides
  - Remove rough grinding burrs
  - Same edge geometry
  - Machine or grind edge profile
- **Similar joint design**
  - Provide backing gas shielding
  - Ensure full penetration weld

Differences: Austenitic vs. Duplex

Duplex weld / HAZ sensitive to:

- Excessive ferrite
- Sigma phase

“You can’t tell from the outside”

Differences Austenitic vs. Duplex

- Qualification extremely important
  - Appearance of weld gives no indication of quality
  - Written procedures and trial welds necessary to assure quality

Differences Austenitic vs. Duplex

- Less thermal expansion - less distortion
- Less hot cracking
- Sensitive to H_2-cracking
  - Remove moisture from joint
  - Store electrodes at elevated temperature
  - Avoid hydrogen in backing or shielding gas

Metallurgy: Phase Balance

- Don’t quench too quickly
- No wash passes or spot welds
- Intermediate heat input
- Filler metal mandatory
- Nickel over-alloyed filler
- Nitrogen in shielding gas is beneficial
- Remove tack welds in final fabrication

Metallurgy: Sigma Phase

- Don’t cool too slowly
- Avoid high heat input
- Inter-pass temperature < 300°F
- Heat input 15 - 60 KJ/inch (2205)
- Qualify all welding procedure
- Qualify weld repairs

Welding Processes for Duplex Stainless Steel

- Shielded Metal Arc Welding:
  SMAW, covered electrodes, “stick”
- Gas Tungsten Arc Welding:
  GTAW, “TIG”
- Gas Metal Arc Welding:
  GMAW, “MIG”
- Flux Core Arc Welding: “FCAW”
- Submerged Arc Welding: “SAW”

2205 Welding

- Always use filler metal, even for repair
- Use 2209 (7 - 9% nickel) filler metal
- Preheating is not necessary
- Heat input 15 - 60 kJ/inch
- Interpass temperature below 300°F
- Post-weld heat treatment is not normally necessary. Above 600°F alpha prime precipitation is a concern (885 embrittlement)

Superduplex Welding

- Always use filler metal, even for repair
- Use 25Cr-10Ni-4Mo-N filler metal
- Preheating is not necessary
- Heat input 15 - 40 kJ/inch
- Interpass temperature below 200°F
- Post-weld heat treatment is not normally necessary. Above 600°F alpha prime precipitation is a concern (885 embrittlement)

Dissimilar Metal Welds

- Duplex can be welded to austenitic stainless steels and carbon steels
- E309LMo/ER309LMo or E2209/ER2209 filler used when welding to austenitic stainless steel
- E309L/ER309L or E309LMo/ER309LMo filler used when welding to carbon steels

Welding Consumables Used for Dissimilar Metal Welding

	2304	2205	25 Cr	Superduplex
2304	2304 2209	2209	2209	2209
2205	2209	2209	25Cr-10Ni-4Mo-N	25Cr-10Ni-4Mo-N
25 Cr	2209	25Cr-10Ni-4Mo-N	25Cr-10Ni-4Mo-N	25Cr-10Ni-4Mo-N
Superduplex	2209	25Cr-10Ni-4Mo-N	25Cr-10Ni-4Mo-N	25Cr-10Ni-4Mo-N
304	309LMo 2209	309LMo 2209	309LMo 2209	309LMo
316	309LMo 2209	309LMo 2209	309LMo 2209	309LMo 2209
Carbon steel	309L 309LMo	309L 309LMo	309L 309LMo	309L 309LMo

Welding Consumables

- Always use a recommended welding product
- Duplex stainless steel weld fillers are slightly overalloyed compared to the base material
- Composition of consumables is chosen to produce correct Austenite/Ferrite balance in duplex stainless steel welds

Duplex Stainless Steel Shielding Gases

Method	Shielding Gases
TIG	Ar or Ar + 2 - 3% N_2 or Ar + 30% He
MIG	Ar or Ar + 2 - 3% N_2 or Ar + 30% He + 1 - 3% CO_2 or Ar + 2 -3 CO_2
FCAW	Ar + 18 - 25% CO_2 or 100% CO_2

Good Welding Qualification

- Toughness
- Corrosion resistance
  - e.g., ASTM A 923
- ASME requirements
- Metallography

➔ **Service relevant properties are most important**

Post Weld Heat Treatment

Only full solution anneal acceptable!

- Not normally necessary, except:
  - Autogenous weld (not recommended)
  - Thick weld section with multiple passes

  to remove sigma phase and restore phase balance

Post-Fabrication Cleaning

- Main Objectives are:
  - Remove heat tint
  - Make sure there is no surface contamination, such as smeared or embedded iron
  - Ensure there is a strong, continuous, protective chromium-rich oxide layer all over the surface

Post-fabrication cleaning treatments

- **Blasting** (eg. glass beads)
  - Local or large area cleaning
- **Grinding** (abrasive discs or flapper wheels)
  - Do not smear (eg. wire brushes) or overheat the surface (eg. worn abrasives or excessive pressure)
- **Pickling** (mixed nitric-hydrofluoric acids)
  - Immersion, spray or paste
- **Electropolishing** (electrocleaning)
  - Site or shop treatment

Better result

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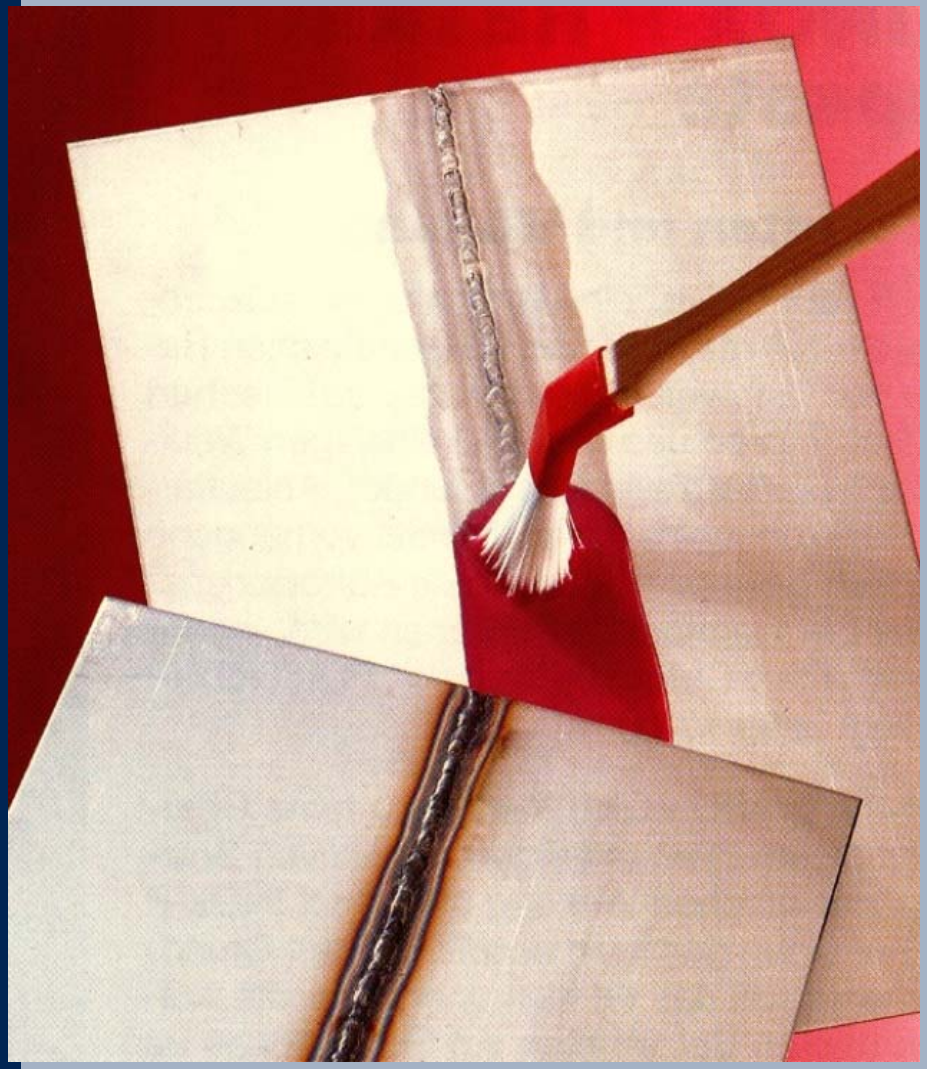
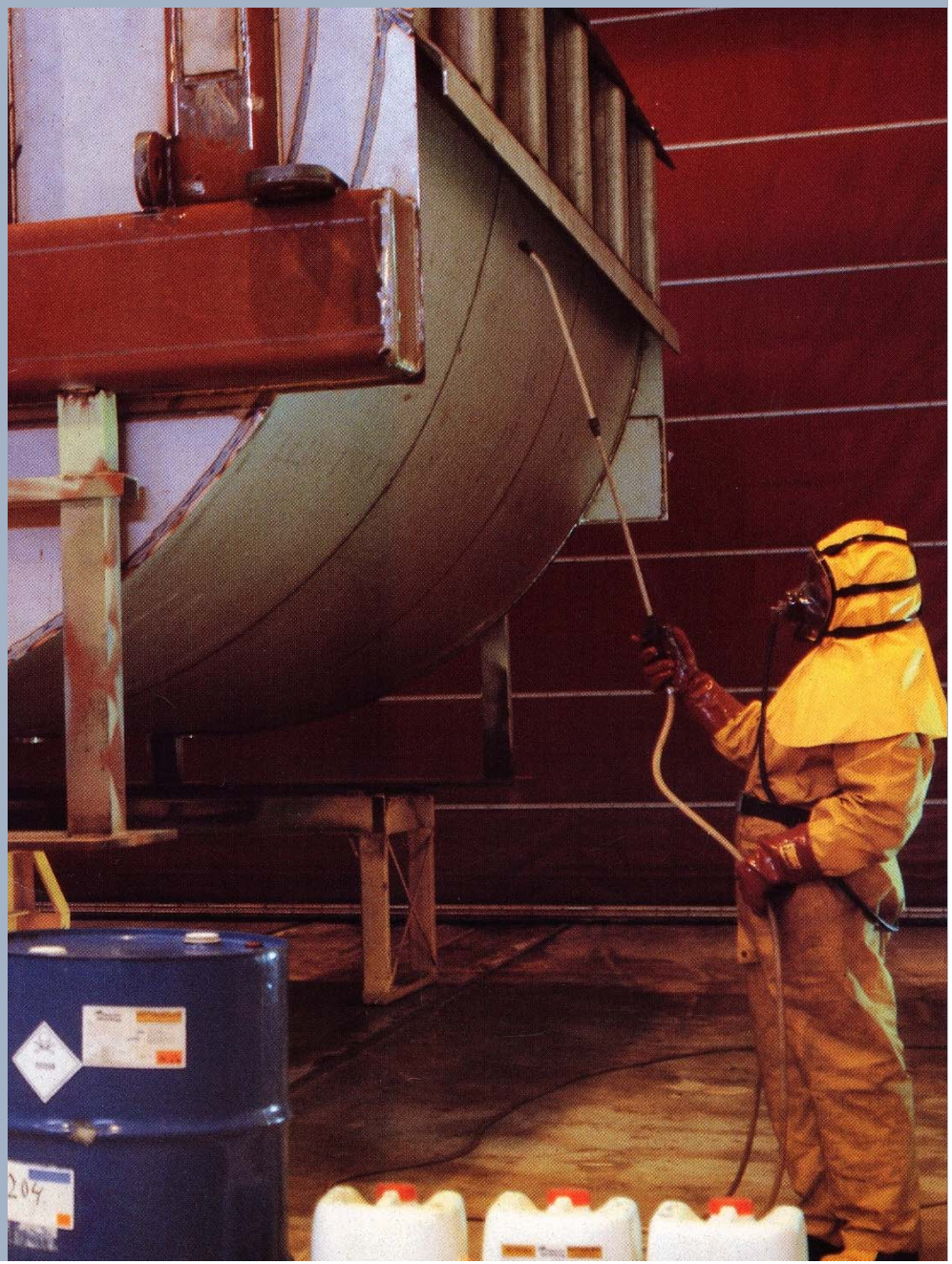


Pickling with paste

Pickling

- Chemical treatment to remove heat tint, and the underlying chromium-depleted layer and surface contamination
- Covered by: ASTM A 380

Spray Pickling

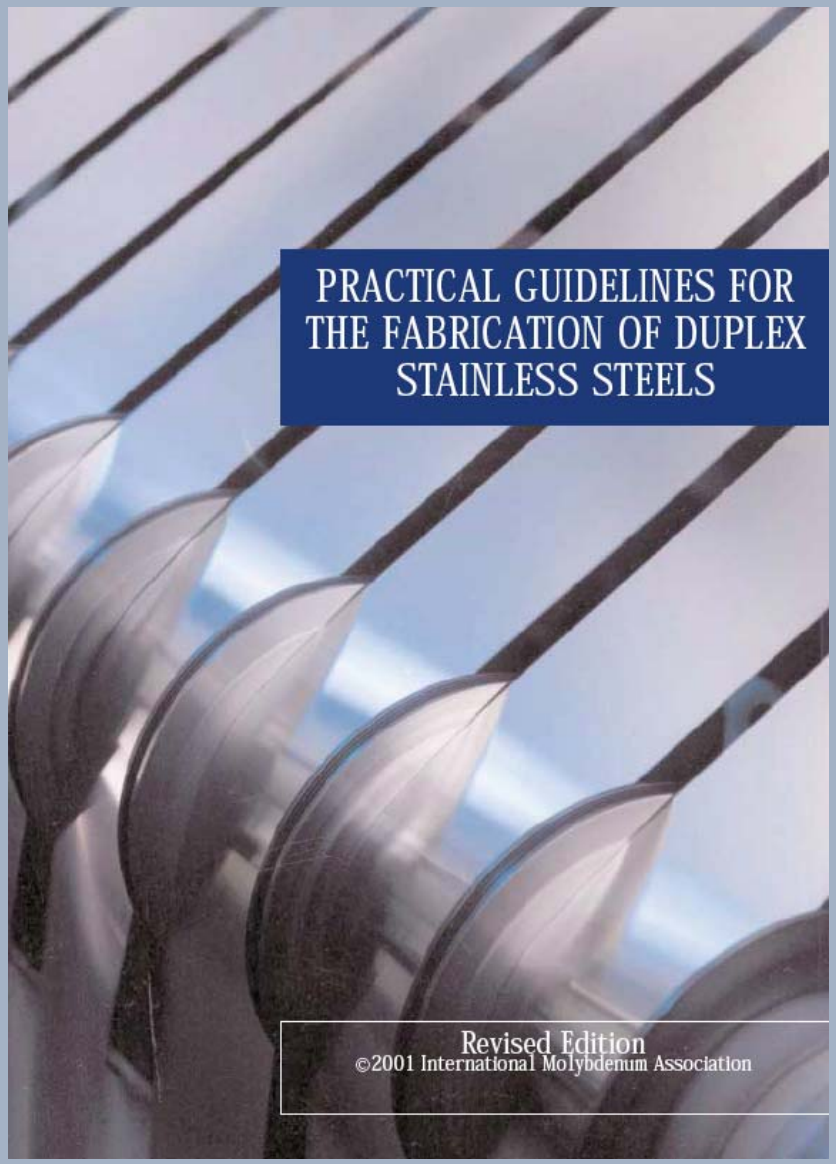


Pickling

Before

After

Duplex Stainless Steel Fabrication Handbook



Publication was revised in 2009 and will be printed by IMOA

New duplex stainless steel grades are included in the revision

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