INTRODUCTION TO STAINLESS STEEL

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SUMMARY

- The BSSA
  - What we do !
- What makes stainless steel stainless: ‘the passive layer’
- 5 Types of Stainless Steel
  - Metallurgy
    - Structure
    - Mechanical and physical properties
    - Applications
- Structure, composition and property factors affecting weldability

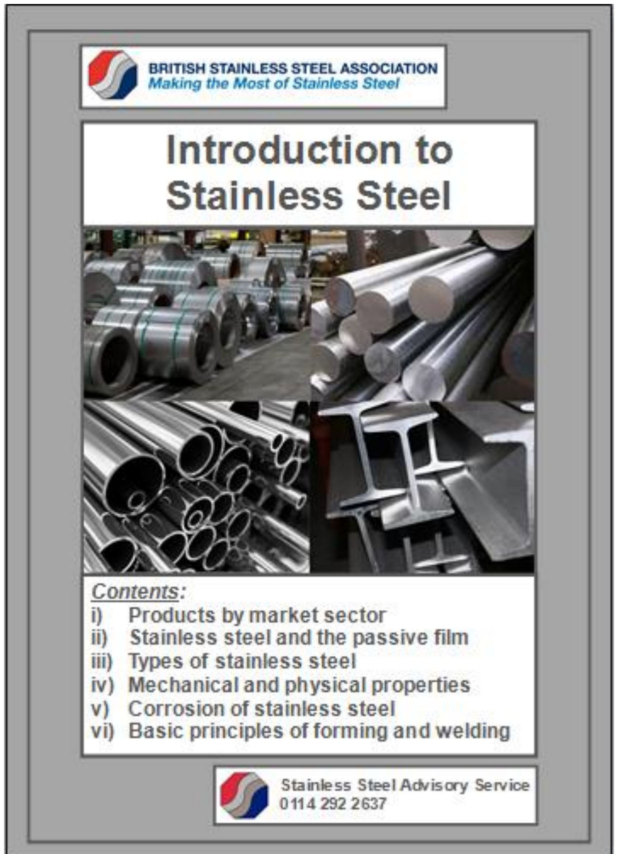
BSSA: WHAT WE DO

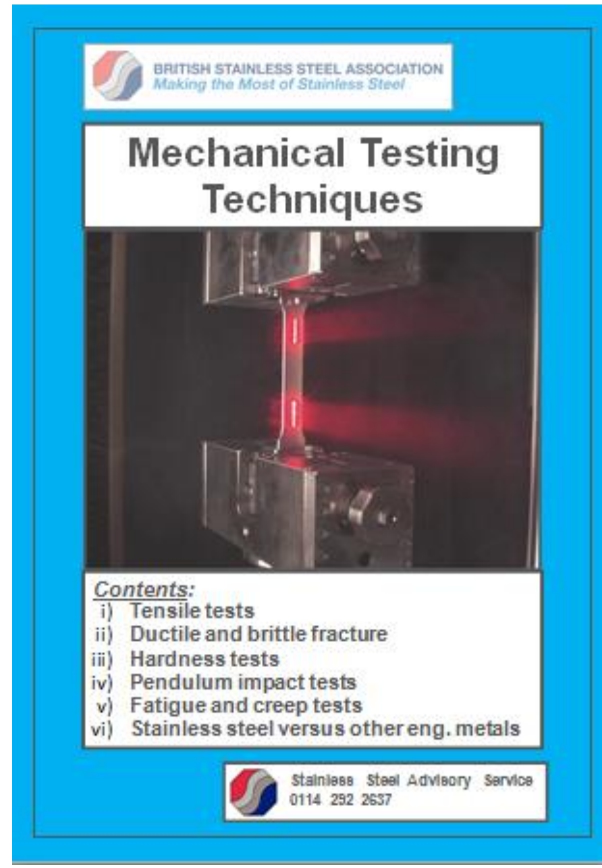
HELP & ADVICE	The Stainless Steel Advisory Service (SSAS) Website: www.bssa.org.uk (>1.5 million hpy) To date, over 42,000 technical enquires answered
TRAINING & EDUCATION	Starter and Advanced Stainless Steel Courses Fabrication Seminars Bespoke in-company Courses Open seminars (e.g. CE Marking), eNewsletters, Information campaigns
EVENTS	Forums Conferences Networking social functions
MARKET DEVELOPMENT	CPDs for architects

BSSA: TRAINING + EDUCATION

2 Current Courses:

1. Intro. to Stainless Steel | **2. Mechanical Testing Techniques**





BSSA: CPDs

- RIBA Approved CPDs
  1. Stainless Steel for Architects
  2. Specifying Stainless Steel for Architectural Applications

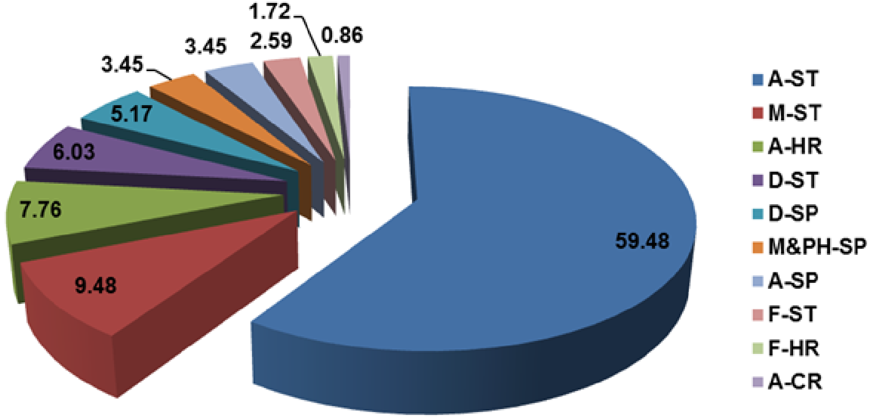
3. Designing Building Exteriors in Stainless Steel

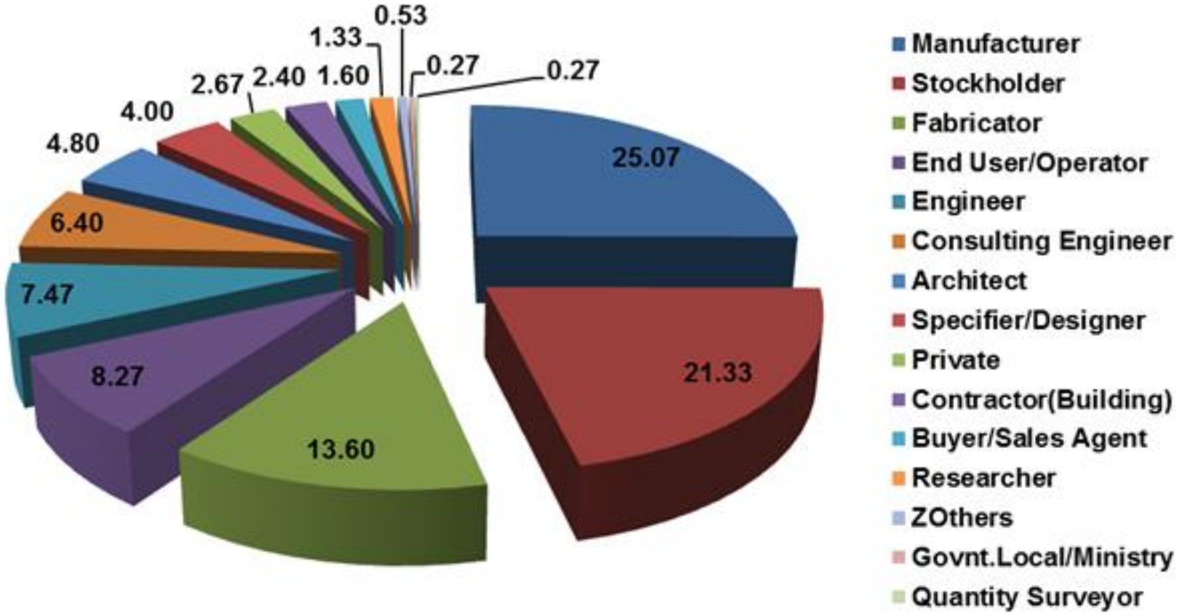
4. Stainless Steel in Swimming Pools

BSSA: TECHNICAL ENQUIRIES

Snap-shot of 2015

>75% concerned with standard grades – technical enquiries from: manufacturers (25%), Stockholders (21%), Fabricators (13%), End users (8%)





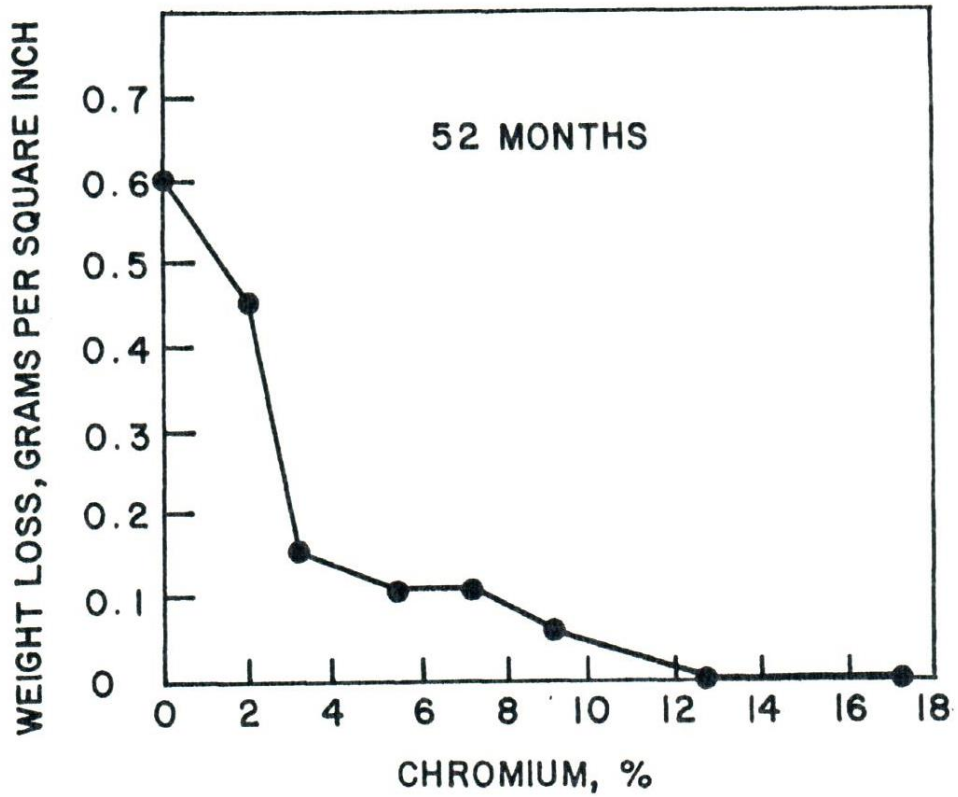
Technical Issues:
Material selection
Specification/grade
Supply of materials
Corrosion
Surface treatment

DEFINITION OF STAINLESS STEEL & THE PASSIVE LAYER

STAINLESS STEEL

- What is a stainless steel ?

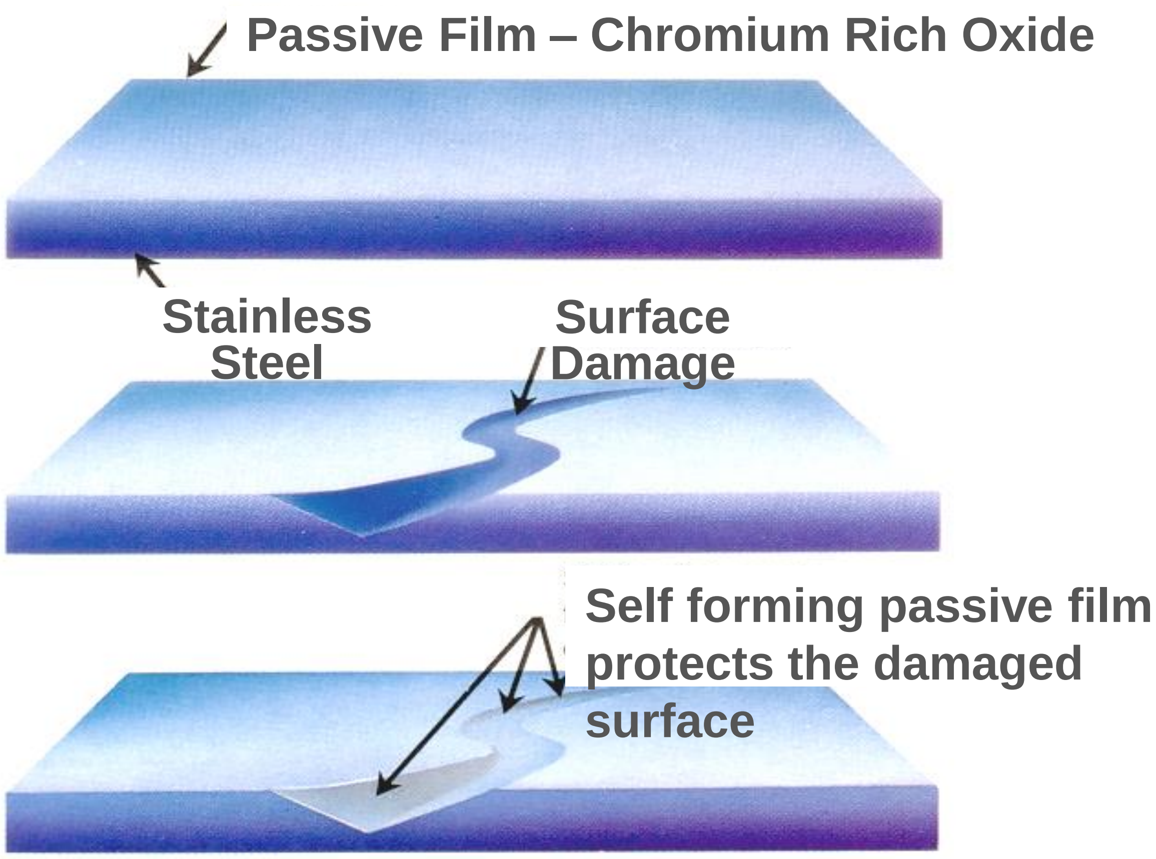
- An increasing wt.% of chromium dramatically reduces atmospheric corrosion until its content is sufficient for stainless steel



- Stainless steels are iron alloys containing a minimum of 10.5wt. % chromium (and ≤ 1.2wt.% C) [BSEN 10088/1]

STAINLESS STEEL: THE PASSIVE LAYER (1)

- What makes stainless steel corrosion resistant ?



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STAINLESS STEEL: THE PASSIVE LAYER (2)

- **Metal + air → metal oxide**
- **Different types of oxide**
  - Iron oxide on carbon steel: porous - allows further oxidation
  - Chromium oxide on stainless steel: not porous, is stable and usually prevents further oxidation
- **Passive layer is very thin – 1/10000 the thickness of human hair ranges from 2/3 to 10's of atomic layers thick**
- **Points to Note!**
  - Passivation is accelerated by oxidising acids e.g. citric or nitric
  - Welding can adversely effect the passive film – depletes chromium from surface
  - Chlorides & reducing acids adversely effect the passive layer
- **No stainless steel resists all environments**

5 TYPES OF STAINLESS STEEL

- Austenitic: most common, ~70% of total usage
- Ferritic: ~20%
- Ferritic-Austenitic (duplex): 3%
- Martensitic: ~5%
- Precipitation Hardened (PH): can be fully austenitic, semi austenitic or martensitic, ~2%

5 TYPES OF STAINLESS STEEL: STRUCTURES

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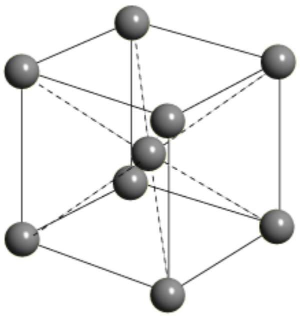
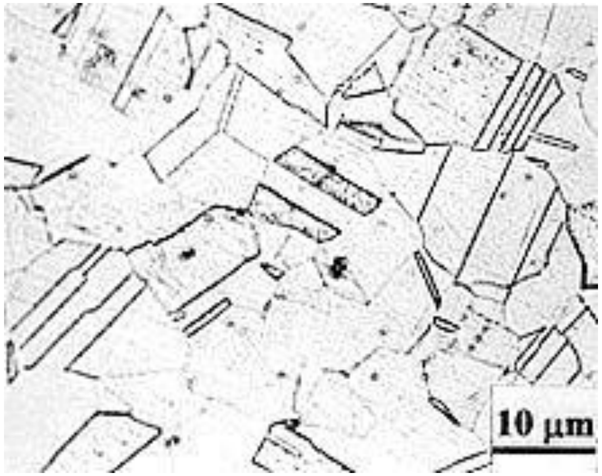


409 Ferritic st/st

316 Austenitic st/st



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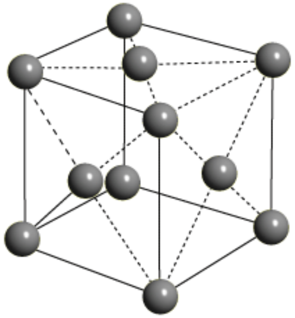
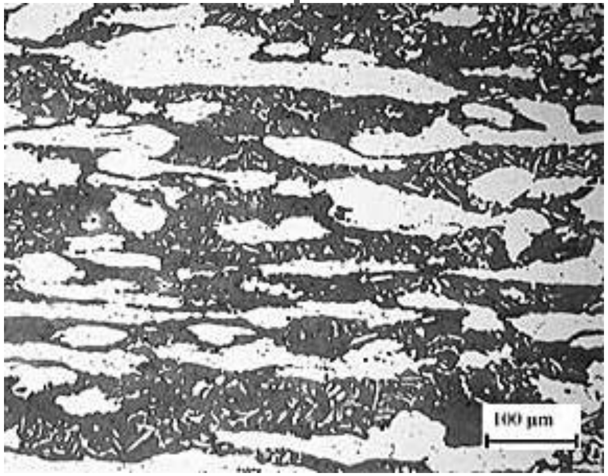
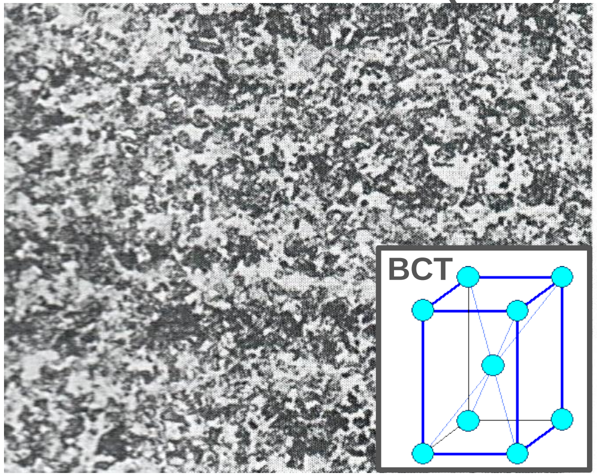


2205 Duplex st/st



403 Martensitic st/st (x400)



Custom 455 PH Steel (x1000)

AUSTENITIC STAINLESS STEELS

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- A closer look ……

No	Advantages	Disadvantages	Applications
1	Easy to Produce	Subject to price swings – Ni cost variable	Sinks, saucepans, cutlery, cladding, handrails, catering surfaces, chemical, pharmaceutical, food processing, oil and gas, street furniture, hospital equipment, MRI scanners, building products e.g. wallties, furnaces, electrical energy, cryogenic storage vessels, springs, rail carriages, high spec exhaust systems, process piping, medical devices, water tubing, nuclear processing, yacht trim
2	Formable – stretch forming & deep draw	High alloy grades very expensive	
3	Weldable thick sections	Not heat treatable in bulk	
4	Low temperature toughness	Low thermal conductivity	
5	Oxidation resistance	Difficult to machine	
6	High alloy grades give high corrosion resistance	High thermal expansion leads to distortion	
7	Strengthened by cold work		
9	Non-magnetic		

FERRITIC STAINLESS STEELS

- A closer look ……

	Advantages	Disadvantages	Applications
1	Formable – deep drawing	Not weldable in thick sections	Washing machine drums, automotive exhaust systems, catering equip., microwave oven linings, cheaper cutlery, hot water tanks, internal decorative tubing, automotive trim, induction heating saucepans, window hinges, ventilation ducting, lift panels, electrical enclosures, coal wagons, initial food handling e.g. sugar beet, containers, bus chassis
2	Oxidation resistance	Not as stretch formable as austenitic grades	
3	High alloy grades giving high level of corrosion resistance	Not as easy to produce	
4	Price stability – low Ni	Not heat-treatable	
5	Similar thermal props. to carbon steels	Poor low temp. toughness	
6	Resistant to stress corrosion cracking		

MARTENSITIC STAINLESS STEELS

- A closer look ……

	Advantages	Disadvantages	Applications
1	Heat treatment gives wide range of props.	Poor weldability in most grades (low carbon grades OK)	Razor strip, high quality knife blades, scalpels, shafts, hydraulic rams, wear resistant plate, oil and gas
2	High strength with moderate toughness at RT	Poor low temperature toughness	
3	Good high temperature strength	Process route , more complex than austenitic	
4	Good for blades	Limited corrosion resistance	
5	Price stability – low Ni		
6	Similar thermal props. to carbon steels		

DUPLEX STAINLESS STEELS

- A closer look ……

No	Advantages	Disadvantages	Applications
1	2 x strength of austenitics, hence thickness and wt. reduction	Complex metallurgy, difficult processing to achieve phase balance	Chemical processing, subsea oil and gas, structural applications, bridges, hot water tanks, pulp and paper, desalination plants
2	Moderate low temperature toughness	More care required in welding	
3	Weldable in thick sections	Higher power needed for forming	
4	Resistance to Stress Corrosion Cracking	More difficult to machine than austenitics (one exception)	
5	Better price stability than austenitic, particularly lean duplex	Limited to 300 deg C maximum	

PH STAINLESS STEELS

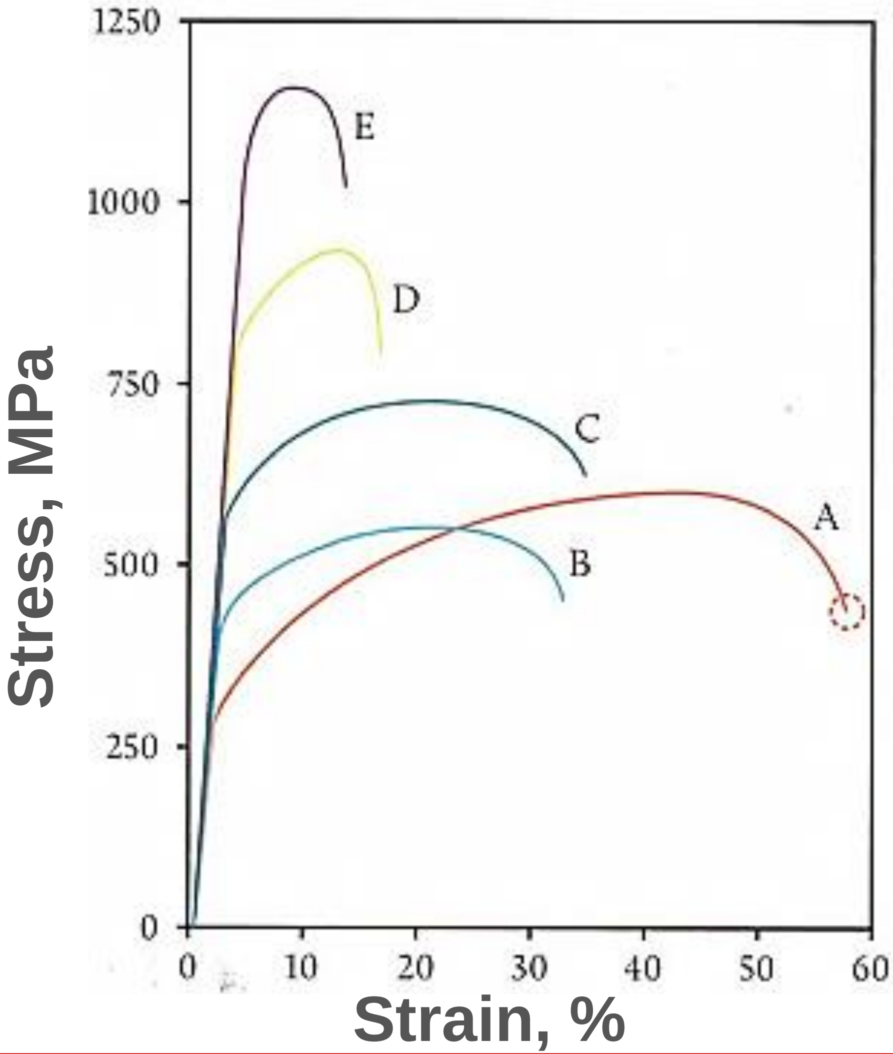
- A closer look ……

	Advantages	Disadvantages	Applications
1	Very high strength and better toughness than martensitic	Quite expensive	pumps, shafts, valves, critical aerospace components
2	Better corrosion resistance than martensitic	Complex process route	
3		Not easy to weld	
4		Not easy to form	

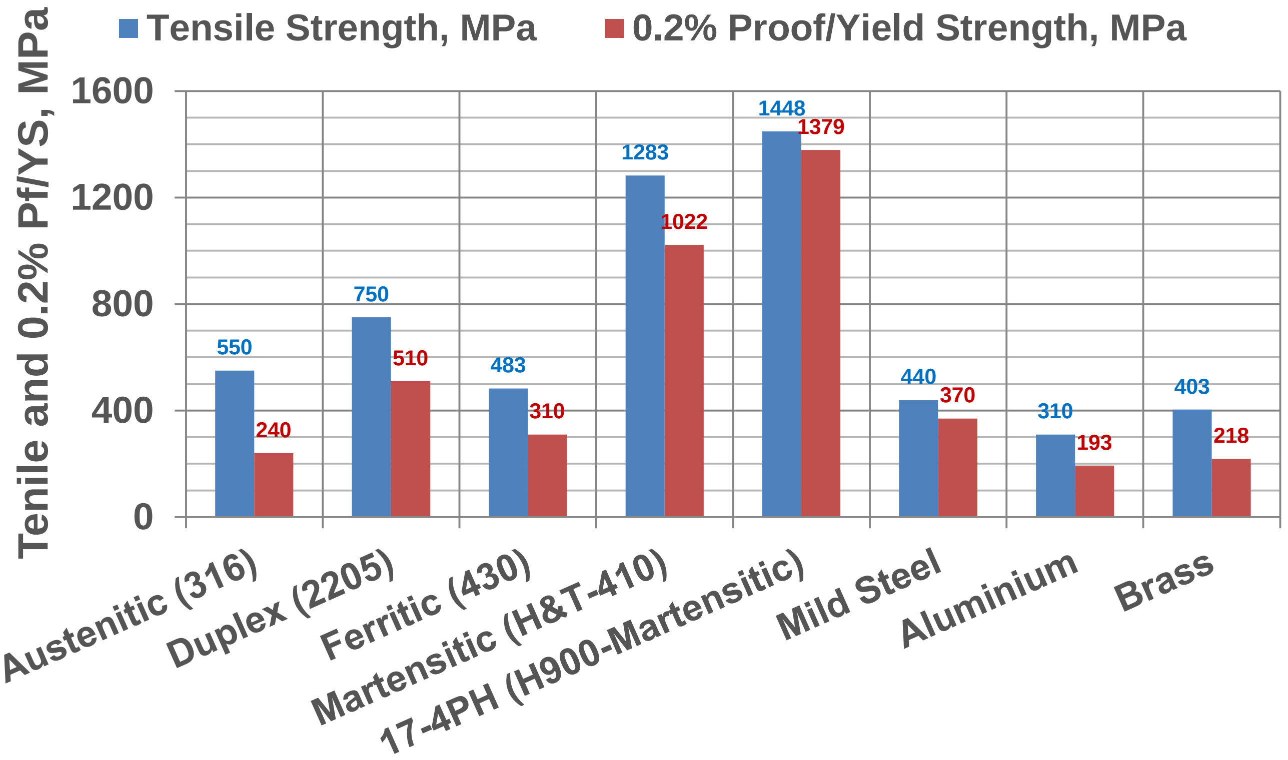
MECHANICAL AND PHYSICAL PROPERTIES

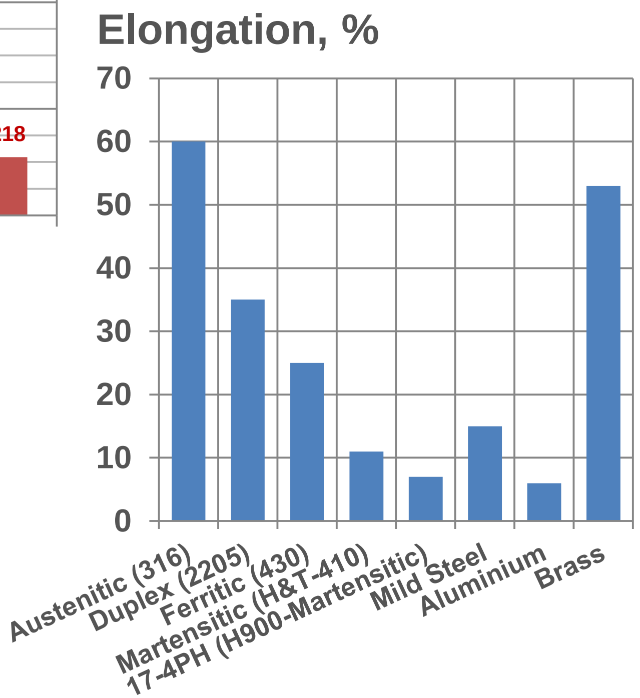
TENSILE STRENGTH

- Tensile Properties
  - A = Austenitic
  - B = Ferritic
  - C = Duplex
  - D = Martensitic
  - E = PH



TENSILE STRENGTH



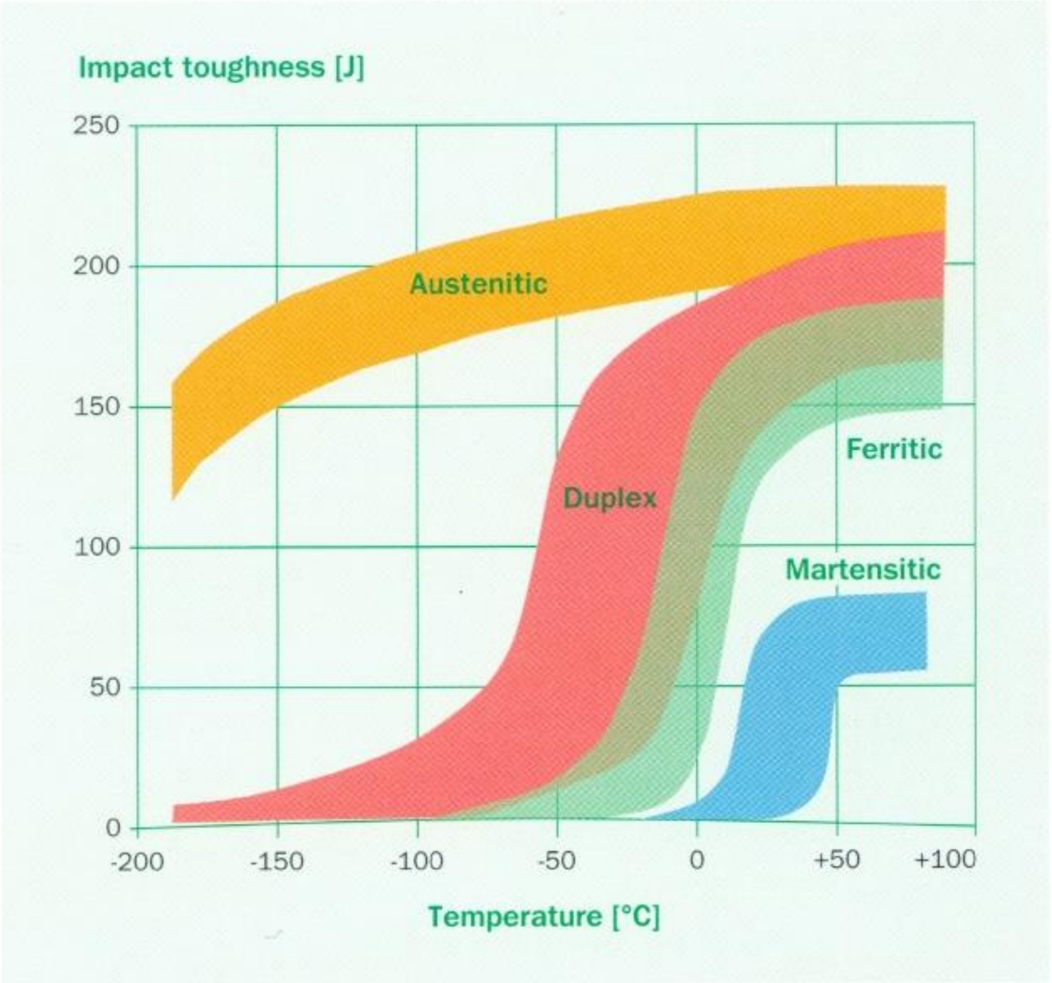


TOUGHNESS PROPERTIES

- **Toughness**
  'Resistance to crack propagation'

  Austenitics very tough even at cryogenic temperatures

  All other stainless types exhibit prominent ductile-brittle transition, typically at sub zero temperatures



FATIGUE & CREEP PROPERTIES

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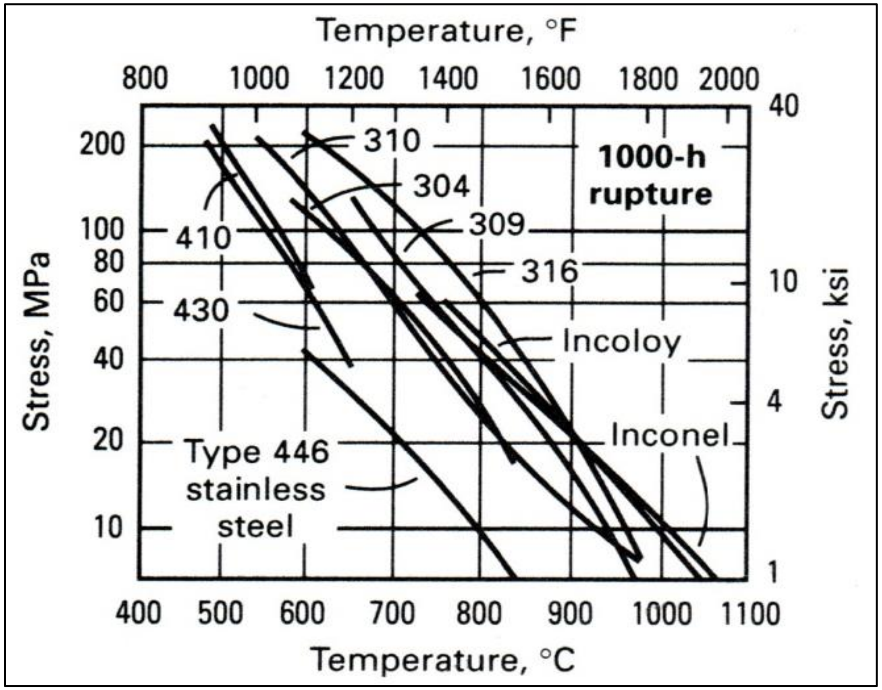
Fatigue Endurance Limit: Austenitic and Duplex

Grade	0.2% PS, MPa	UTS, MPa	Fatigue Limit, MPa	Fatigue / UTS Ratio
1.4301 (304)	210	520	234	0.45
1.4401 (316)	220	520	234	0.45
1.4462 (2205)	460	640	384	0.60

Stress for rupture in 1000hr: Martensitic, Ferritic, Austenitic



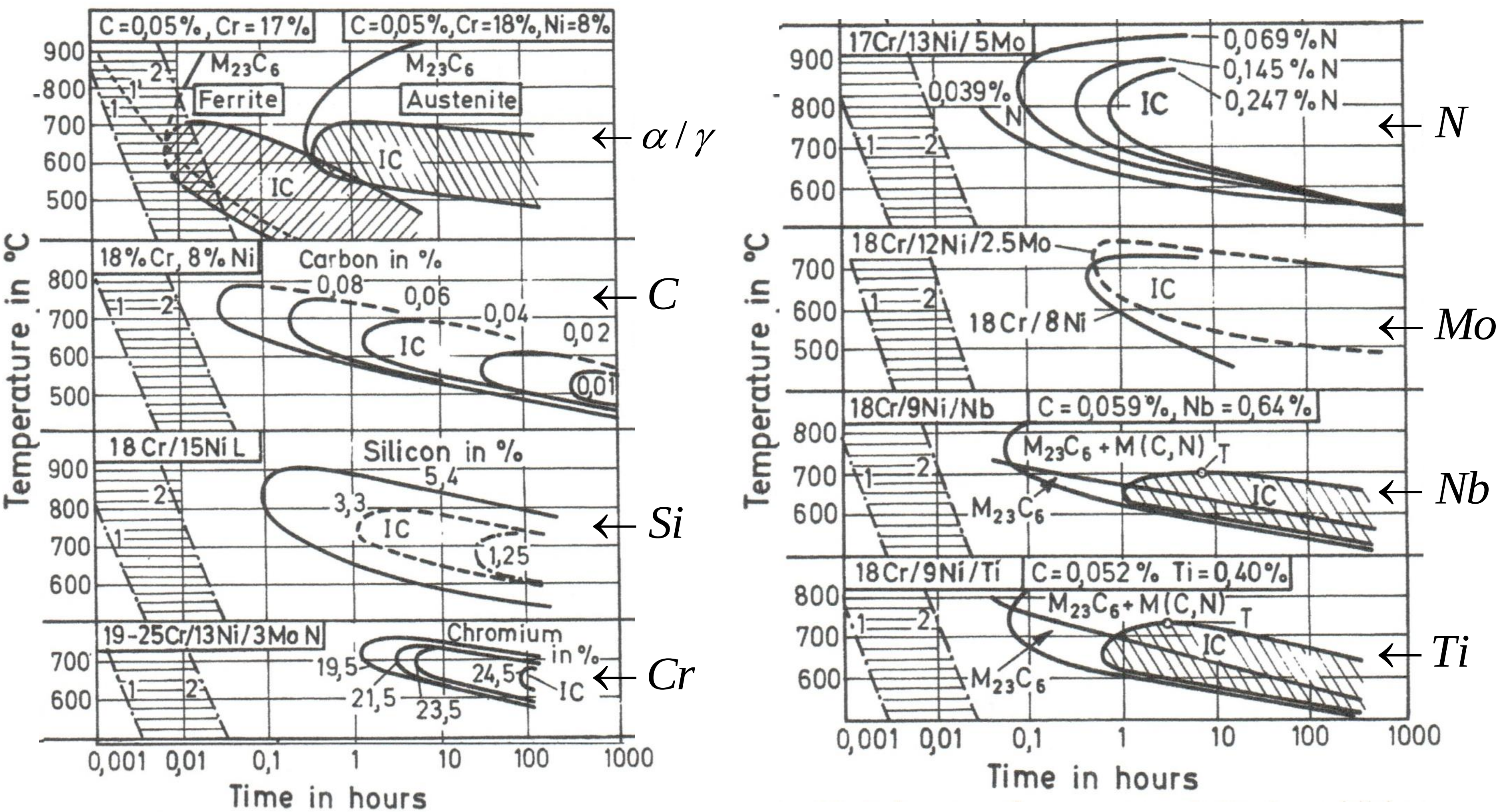
THERMAL PROPERTIES

Grade	Thermal Expansion (10^{-6} K^{-1})	Thermal Conductivity (W m^{-1} K^{-1})	Density (kg m^{-3})
1.4016 Ferritic	10.0	25	7.7
1.4057 Martensitic	10.0	25	7.7
1.4301 Austenitic	16.0	15	7.9
1.4462 Duplex	13.0	15	7.8
1.4542 PH	10.9	16	7.8

Grade	Thermal Conductivity	Thermal Expansion
Mild Steel	1	1
304	4	1.5
430	3.8	0.9

FACTORS AFFECTING WELDABILITY

WELDING ISSUES: ‘SENSITIZATION’ AND IC



WELDABILITY OF AUSTENITIC STAINLESS STEEL

- Positive factors
  - Low carbon – reduces risk of sensitization
  - Single phase – no concern about structure changes
  - No preheat or post weld heat treatment
  - Low grain growth-weld toughness retained in large sections

- Negative Factors
  - High thermal expansion and low thermal conductivity
  - Solifidification cracking – composition balanced to give 5-10% ferrite
  - Risk of distortion in thin sections

WELDABILITY OF FERRITIC STAINLESS STEEL

- Positive factors
  - Low carbon – reduces risk of carbide formation
  - Single phase
  - Lower thermal expansion and higher thermal conductivity hence lower risk of distortion
- Negative Factors
  - High grain growth - loss of weld toughness in thick sections
  - Exception 1.4003 (S40977) – low carbon martensite allows welding of thick sections

WELDABILITY OF DUPLEX STAINLESS STEEL

- Positive factors
  - Part austenitic – relative good toughness in thick sections down to minus 80ºC
- Negative Factors
  - Complex metallurgy, for phase balance - tight control of welding parameters required
  - Embrittling phases relatively easy to form
  - Potential for loss of corrosion resistance and mechanical properties
  - Specific weld and welder qualification required

WELD RELATED PROPERTIES FOR FERRITIC STAINLESS STEEL

- Positive factors
  - Low carbon – reduces risk of carbide formation
  - Single phase
  - Lower thermal expansion and higher thermal conductivity
  - Leading to <u>reduced distortion</u>
- Negative Factors
  - High grain growth - loss of weld toughness in thick sections
  - Exception 1.4003 (S40977) – low carbon martensite allows welding of thick sections

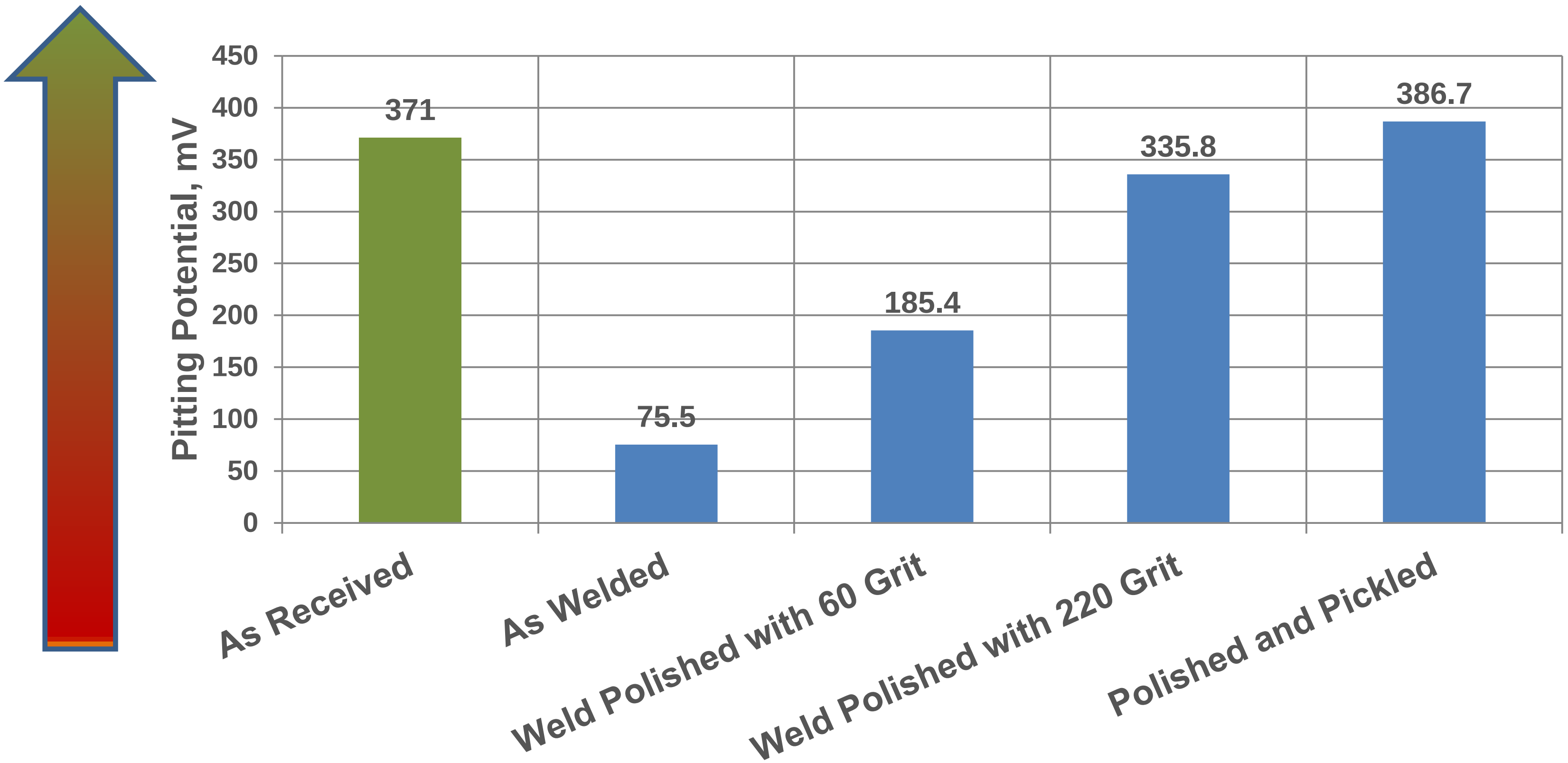
WELDING STAINLESS TO STAINLESS: RULES OF THUMB

- **Dissimilar Welding**
  - Choice of filler usually determined by the more highly alloyed metal e.g. when welding 1.4307 (304L) to 1.4404 (316L) for example, 19Cr12Ni3Mo type filler used
- **Ferritic Steels**
  - When welding ferritic grades, austenitic fillers are often selected to improve mechanical properties
- **Superaustenitic grades**
  - For superaustenitic grades, nickel-base fillers over alloyed with molybdenum are often used to compensate for segregation - reduce the amount of intermetallic phases !
- **High Temperature Austenitics**
  - To avoid the detrimental effect of secondary phases precipitating at 650-960°C specially designed fully austenitic fillers (253 MA-NF) can be used

WELDING STAINLESS TO MILD STEEL: RULES OF THUMB

- When Welding Stainless Steel to Mild Steel:-
  - To optimise crack resistance use over alloyed and high ferrite electrode (23Cr12Ni or 23Cr12Ni2Mo)
  - When welding stainless steel to mild or low alloy steels reduce weld dilution as much as possible. Limit heat input to 1.4kJ/mm and interpass temperature must be <150^{o}C
  - Due to risk of pore formation avoid welding to mild steel that has a coating of prefabrication primer
  - Where High temperature applications (creep properties) are important use nickel base fillers to minimise carbon diffusion from mild steel into the weld metal – this can reduce strength of HAZ in mild steel

EFFECT OF POST WELD CLEANING



Recommended practice is to clean welds
In practice, many welds are left untreated - very light tinting, non-aggressive environments, invisible applications