

Title	Uuden sukupolven ferriittiset ja duplex- ruostumattomat teräkset: Esitutkimus hitsien mekaanisista ja käyttöominaisuuksista
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Uuden sukupolven ferriittiset ja duplex-ruostumattomat teräkset: Esitutkimus hitsien mekaanisista ja käyttöominaisuuksista

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**Suomen hitsaus- ja liittämisinstituutin
yhteisfoorumi**

Tampere 25.10.2012

Presentation outline

1. Introduction
2. Base materials
3. Welding
4. Corrosion behaviour
5. Mechanical behaviour
6. Microstructural characterisation
7. Summary
8. Acknowledgements

1. Introduction

- Project background:
 - Lo-Ni stainless demand grows in pulp&paper and process industries
 - (Lean) duplex, Mn-alloyed austenitics and ferritics: lower alloying cost
 - !! Missing: Comparable corrosion data to traditional Hi-Ni austenitics
 - !! Missing: Codes of practice for welding in demanding applications
- Objectives:
 - To study the use of new advanced stainless steels for the existing applications and explore new ones
 - Demanding process equipment service
 - Less aggressive structural applications
 - Other, non-process applications
 - Special attention to interdependencies between fabrication processes (e.g. welding) and corrosion resistance

1. Introduction (2)

- Scientific & technical goals:
 - Knowledge on localised corrosion and repassivation behaviour in chloride-sulphate solutions, particularly
 - Effect of concentration due to evaporation
 - Crevice corrosion phenomena and behaviour in sheet metal structures, such as metal sandwich panels
 - Understanding the interactions between weld metallurgy, structural behaviour and corrosion resistance of welded joints
 - Mn and/or Lo-Ni alloyed stainless steels
 - Mo alloyed ferritics in pulp & paper and process industry environments and/or structures operating in such environments
 - Welding procedures to ensure of corrosion & mechanical properties
 - Processes, filler metals, post-weld treatments & their combinations
 - Comparable or better corrosion resistance than traditional Cr-Ni grades
 - Fracture behaviour fundamentals of new grades in structural applications

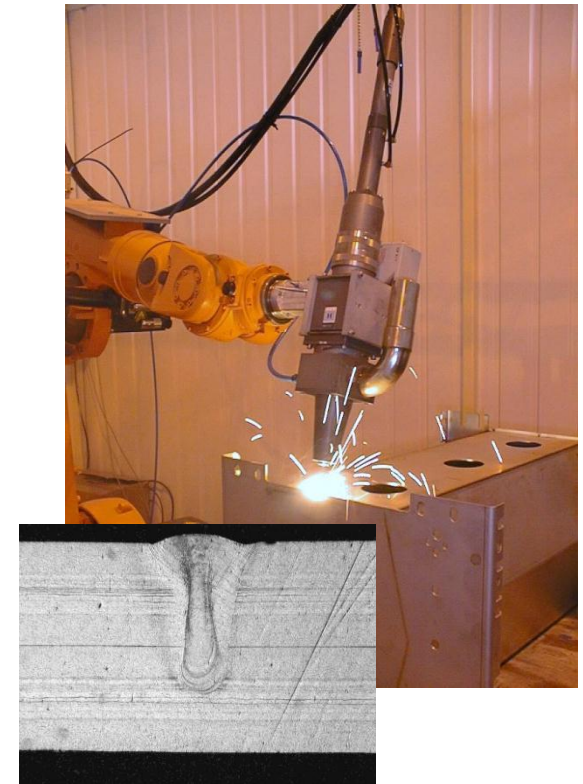
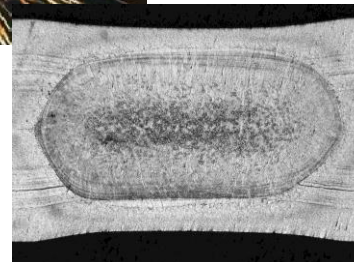
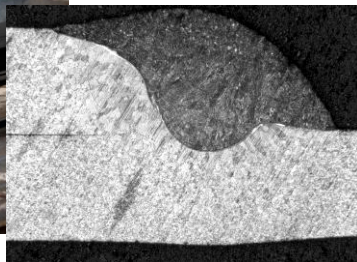
2. Base materials

Grade EN	Type	R _{p0.2} (MPa)	R _m (MPa)	Potential applications	Replacing
1.4318 X2CrNiN18-7 (2H)	Lo-Ni, Hi-N austenitic	591	922	Lesser corrosive applications, e.g. ambient service structures	Traditional Cr-Ni austenitics
1.4372 X12CrMnNiN17-7-5	Mn alloyed austenitic	428	754		
1.4509 X2CrTiNb18	Double stabil- ised ferritic	373	477		
1.4521 X2CrMoTi18-2	Mo alloyed, double stabilised ferr.	402	547	Paper machine environment (e.g. splash zones)	1.4404
1.4162 X2CrMnNiN21-5-1	Mn alloyed Hi- N "Lean Duplex"	568	770	Process industry: high strength & corrosion	1.4404/ 1.4432
1.4432 X2CrNiMo17-12-3	Austenitic	284	582	Established workhorse in process service	Reference

- All materials 2 mm sheet in soft 2B delivery condition except 1.4318 (2H)

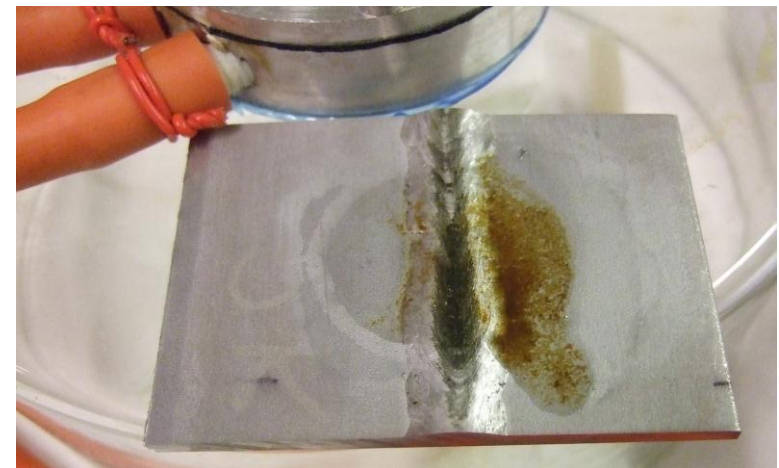
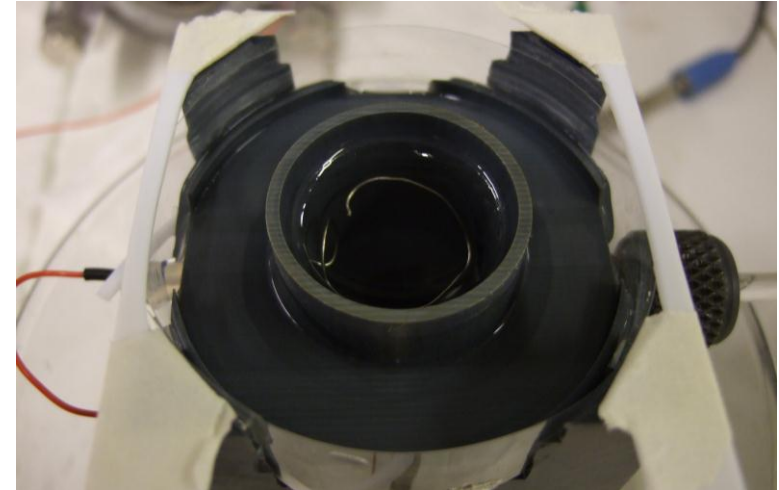
3. Welding

- Thin sheet feasible welding methods selected
 - Pulsed MAG welding with
 - LDX2101 filler metal for 1.4162
 - 316LSi filler metal for other BM's
 - Resistance spot welding (RSW)
 - Autogenous Nd:YAG laser welding (LBW)



4. Corrosion behaviour

- Critical pitting temperature tests
 - Modified standard ASTM G150-99
 - Test surface area 6.6 cm²
 - 1M NaCl solution
 - Tests started at 0 °C
 - Temperature ramp 1 °C/min
 - Constant anodic potential 645 mV vs. Ag/AgCl reference electrode
 - The CPT point:
 - When rapid current increase occurs
 - OR
 - When current density > 100 μA/cm²



4. Corrosion behaviour

Materials	Critical pitting temperature (CPT), °C			
	Base material	LBW circle	RSW spot	MAG fillet
1.4318	12 (1.6)	< 10 (4.0)	< 10 (3.6)	< 10 (1.6)
1.4372	< 10 (3.6)	< 10 (1.9)	< 10 (2.6)	< 10 (1.8)
1.4509	< 10 (0.9)	< 10 (1.9)	< 10 (6.3)	< 10 (1.3)
1.4521	< 10 (0.8)	14 (5.3)	15 (0.8)	< 10 (1.2)
1.4162	19 (0.9)	23 (1.0)	23 (1.3)	14 (1.9)
1.4432	15 (1.0)	15 (1.1)	17 (0.6)	16 (1.0)

- Standard deviations in the parentheses
- All materials used as 2 mm sheet in soft 2B delivery condition except 1.4318 (2H)

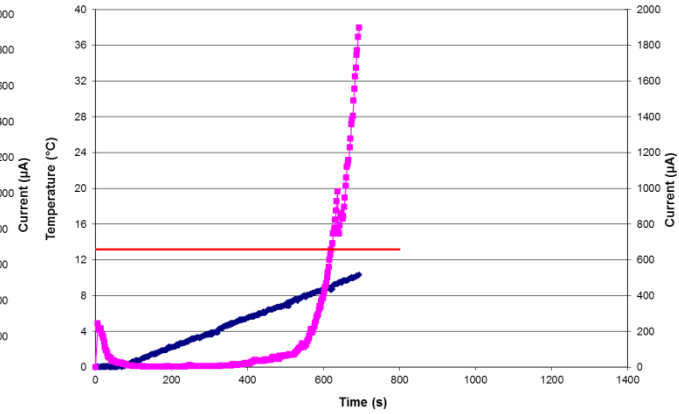
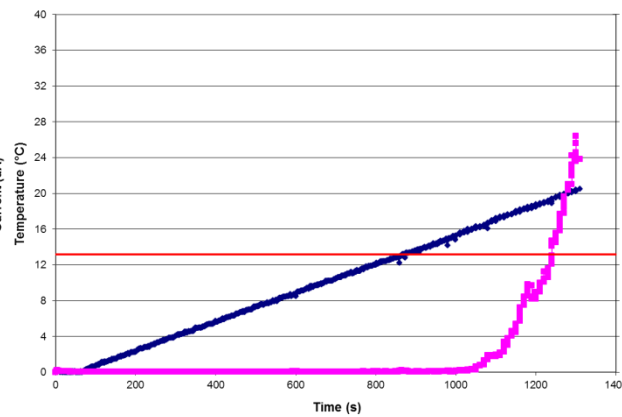
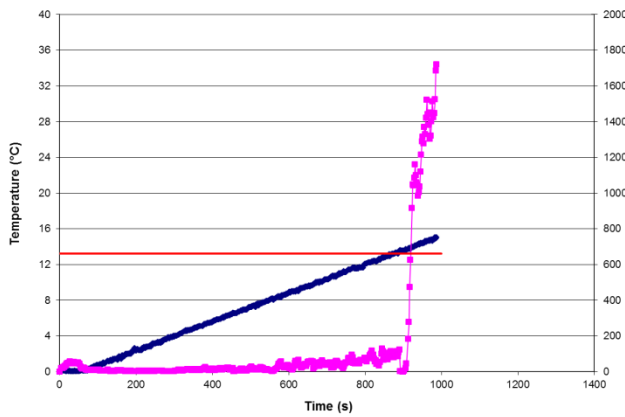
4. Corrosion behaviour

1.4432

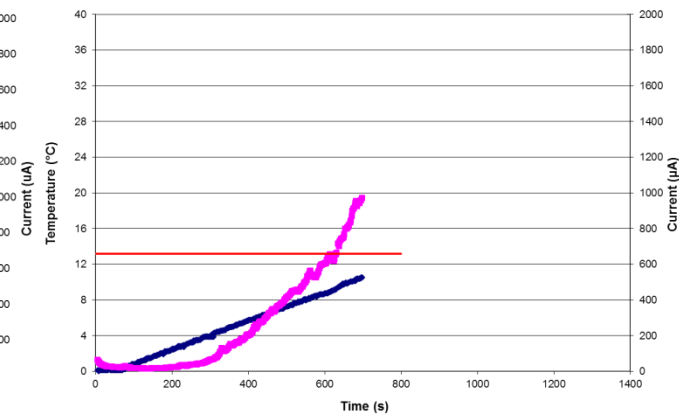
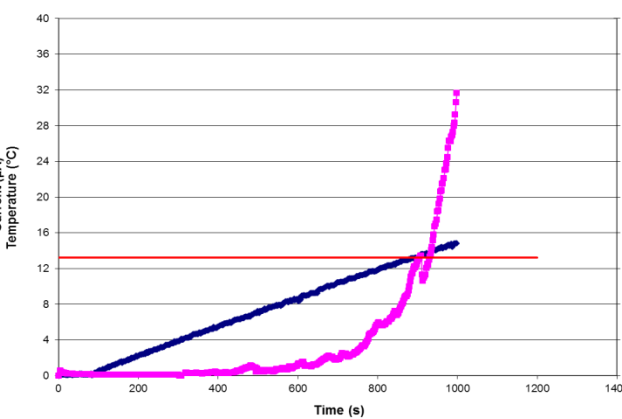
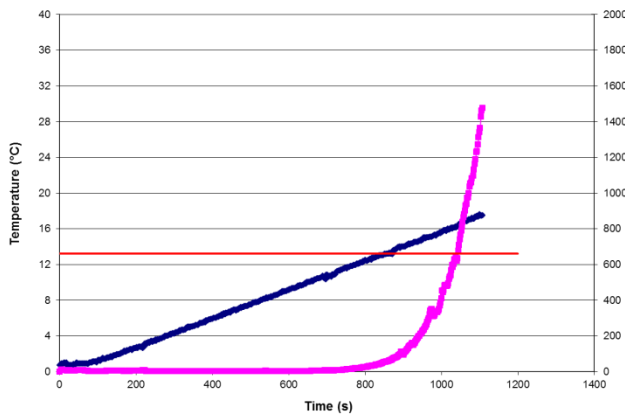
1.4162

1.4521

Base material

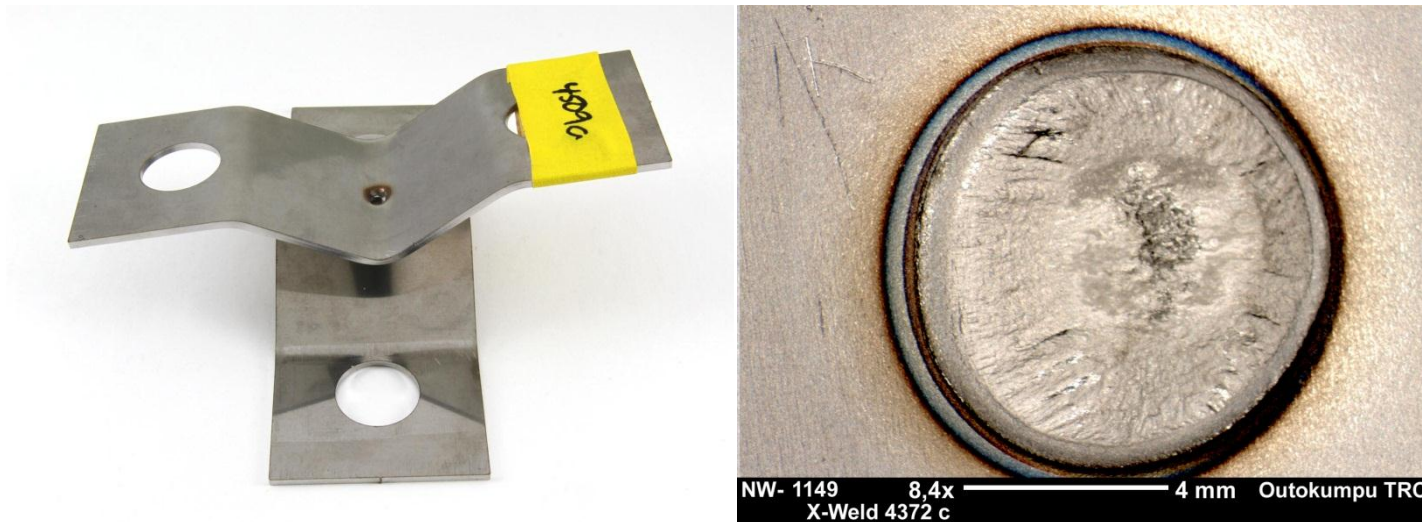


MAG weld



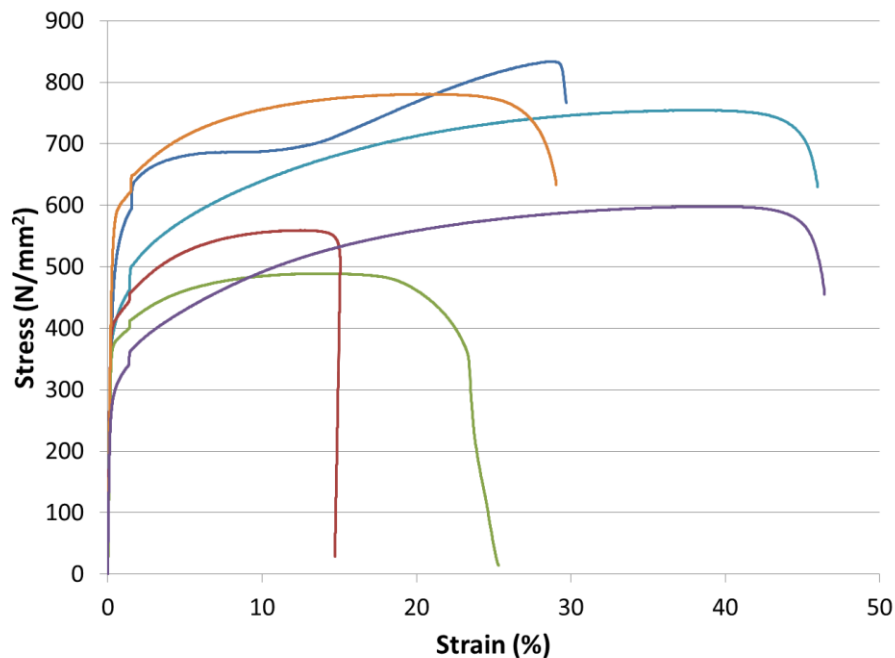
5. Mechanical behaviour

- Three types of mechanical testing
 - Transverse tensile testing for LBW & MAG butt joints (EN 895)
 - Cross-tension for circular LBW & RSW lap joints (EN ISO 14272)
 - Shear tensile for circular LBW & RSW lap joints (EN ISO 14273)

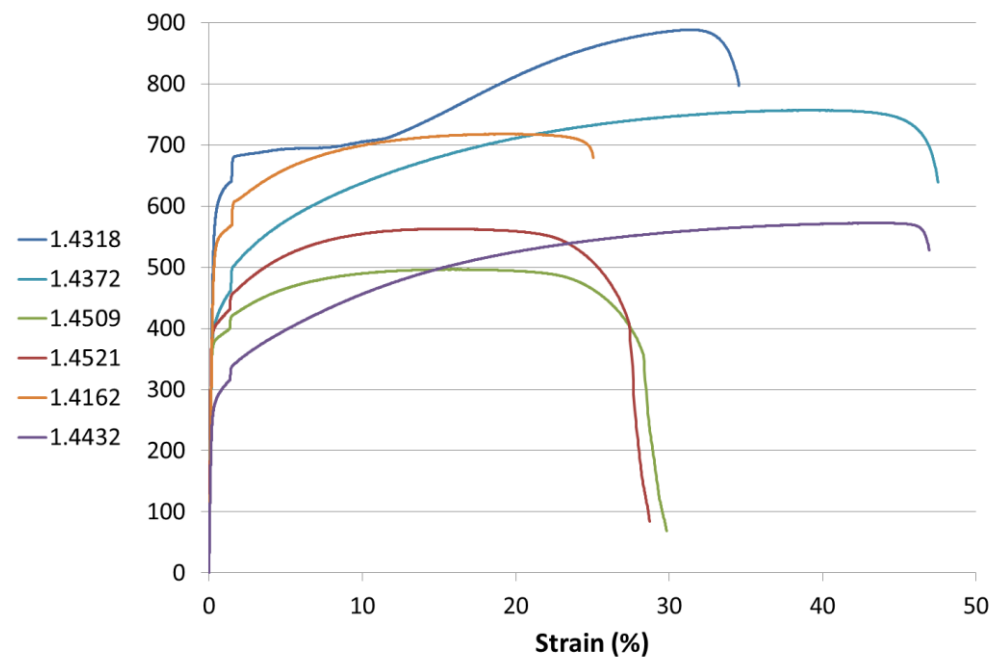


5. Mechanical behaviour: butt tensile

- Typical MAG butt welds
 - Filler metal 316 LSi and LDX2101 (23Cr-7Ni-N)



- Typical laser butt welds
 - Typical curves



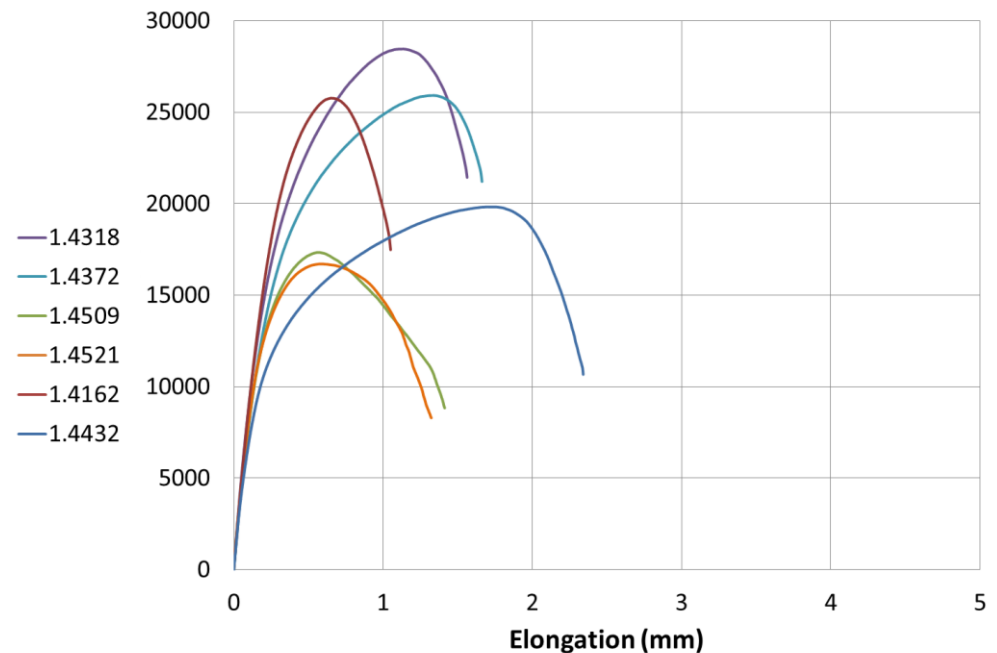
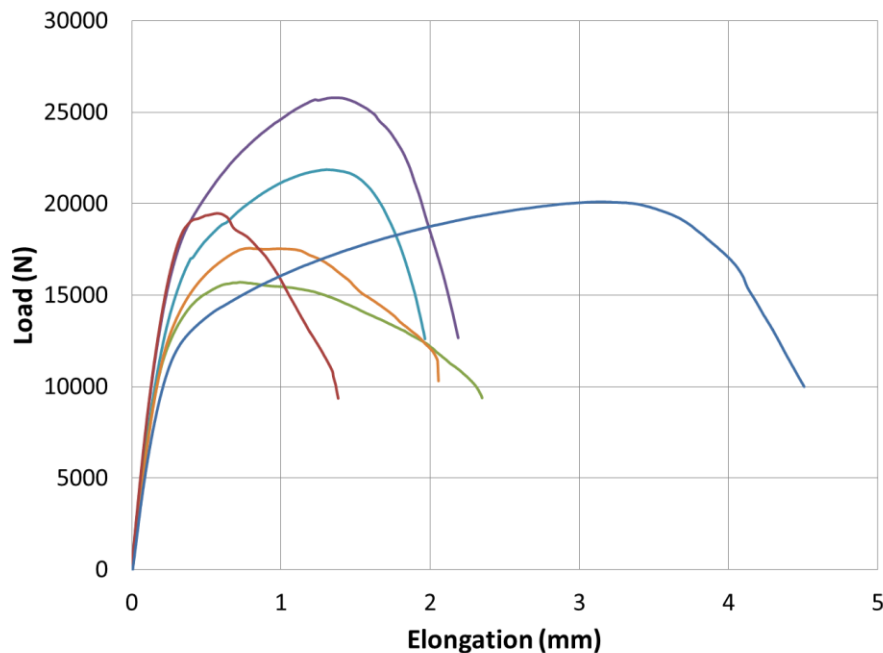
5. Mechanical behaviour: butt tensile

Materials		Weld	N	R _{p0.2} (N/mm ²)	R _m (N/mm ²)	A ₅₀ (%)	Failure location
Base	Filler						
1.4318	316LSi	MAG	6	494	835	30	FL/BM
	-	LBW	4	583	892	35	HAZ
1.4372	316LSi	MAG	3	398	759	47	BM
	-	LBW	4	411	756	48	BM
1.4509	316LSi	MAG	3	374	489	25	BM
	-	LBW	4	379	496	30	BM
1.4521	316LSi	MAG	3	407	559	17	BM
	-	LBW	4	401	563	28	BM
1.4162	LDX2101	MAG	3	575	782	28	BM
	-	LBW	4	539	722	25	WM
1.4432	316LSi	MAG	3	289	598	46	BM
	-	LBW	4	282	581	51	BM/WM

- FL = fusion line; BM = base material; WM = weld metal

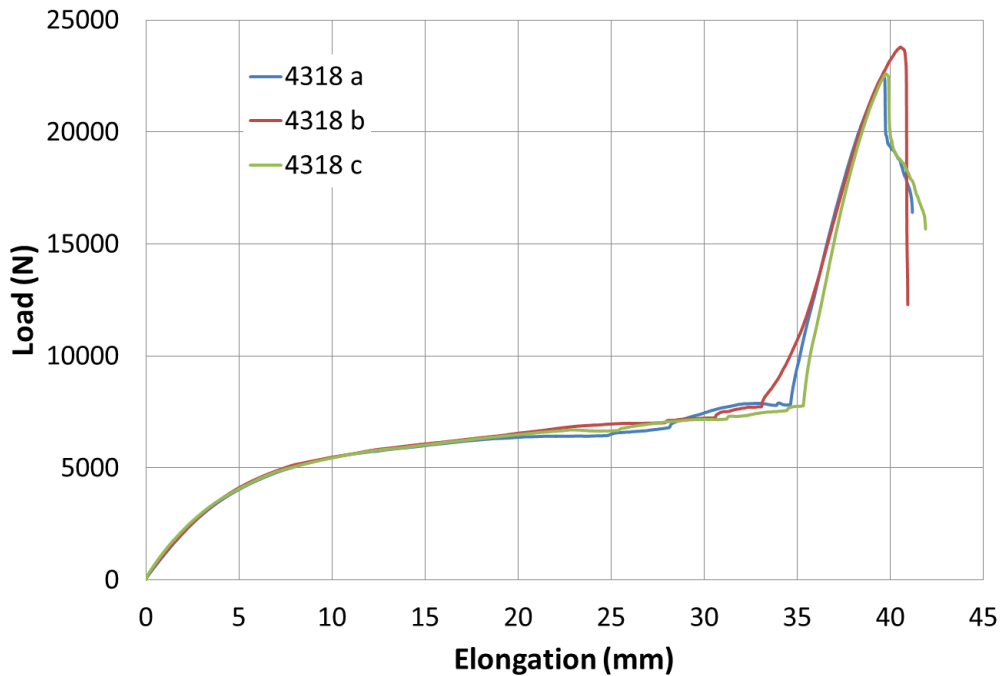
5. Mechanical behaviour: shear tensile

- Typical resistance spot weld
 - $\varnothing \sim 7$ mm "solid spot" weld
 - $A_{\text{weld}} \approx 38 \text{ mm}^2$
- Typical laser circle weld
 - $\varnothing 7$ (o.d.) \times 5 (i.d.) circle
 - $A_{\text{weld}} \approx 18 \text{ mm}^2$

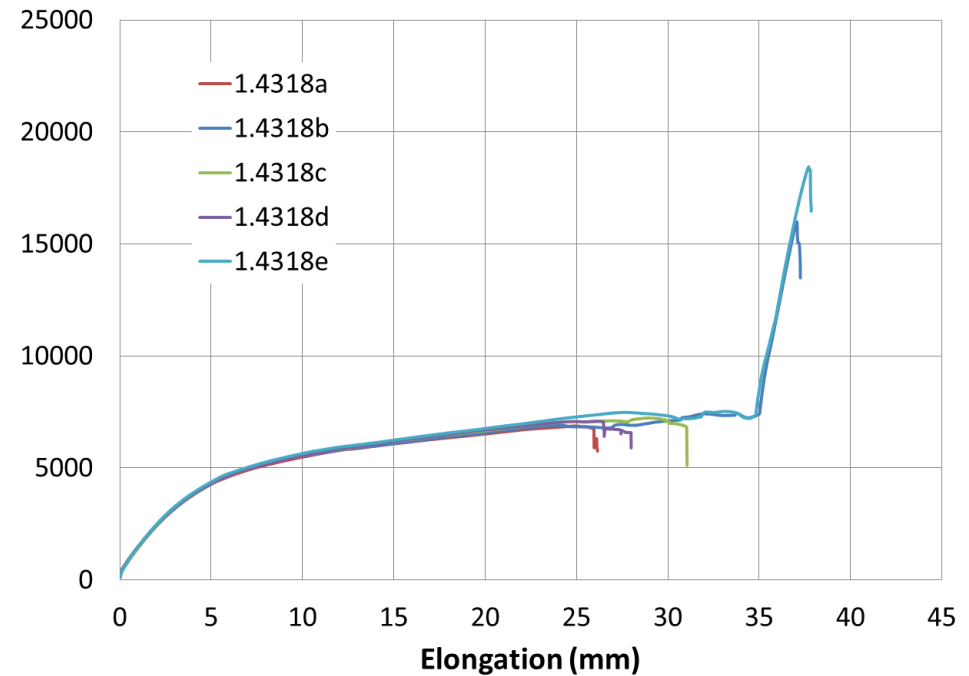


5. Mechanical behaviour: cross tension

1.4318 RSW

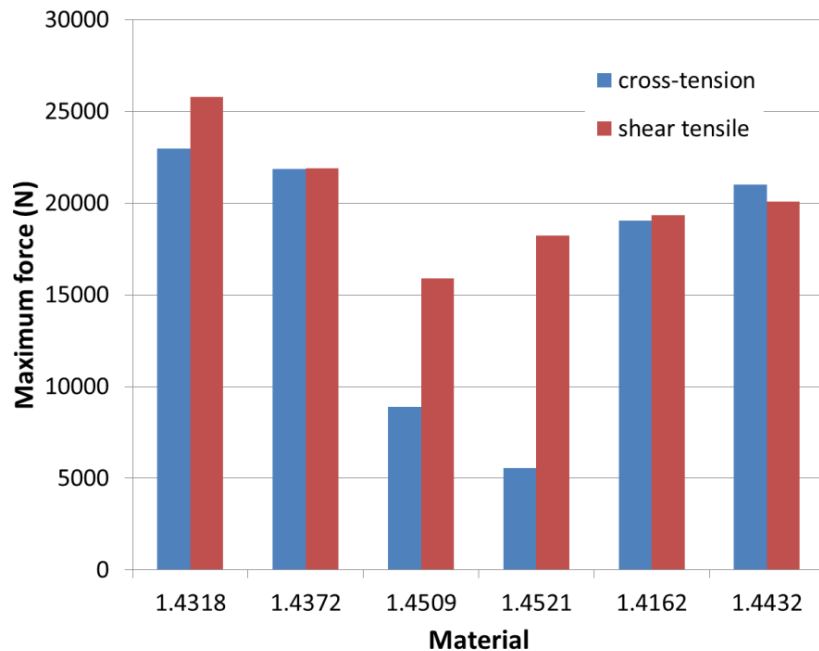


1.4318 LBW

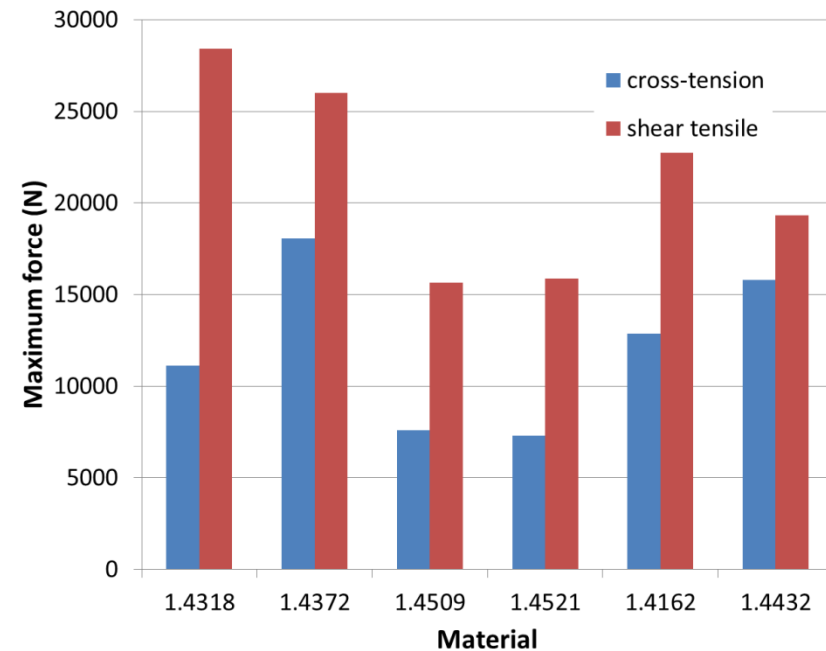


5. Mechanical behaviour: cross tension

- Cross-tension vs. shear tensile: RSW



- Cross-tension vs. shear tensile: circle LBW

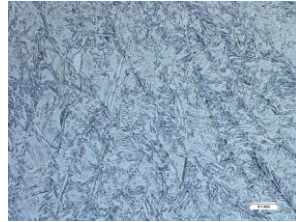


6. Microstructural characterisation

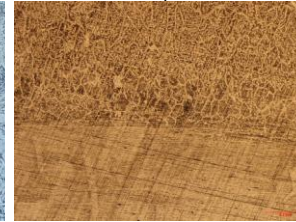
1.4162, Ring laser weld



MAG weld



Resistance spot weld



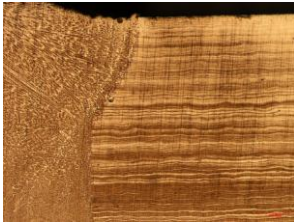
1.4162, Single straight laser weld



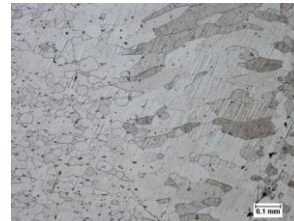
1.4318



1.4372



1.4509 Laser weld



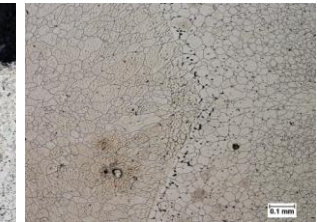
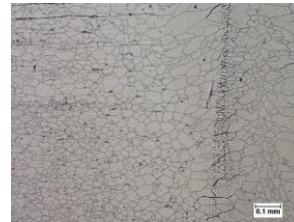
MAG weld



Resistance spot weld



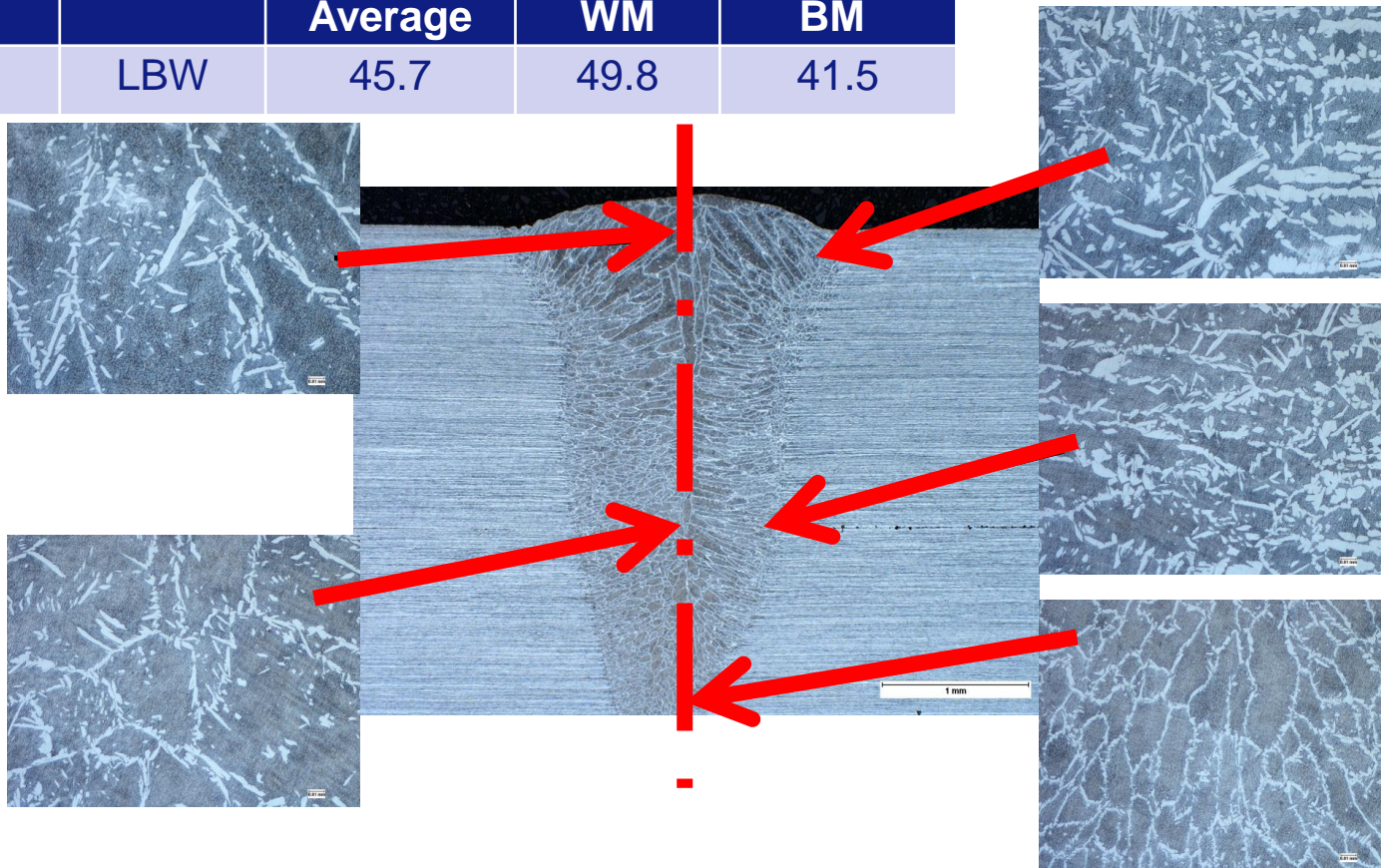
1.4521



6. Microstructural characterisation

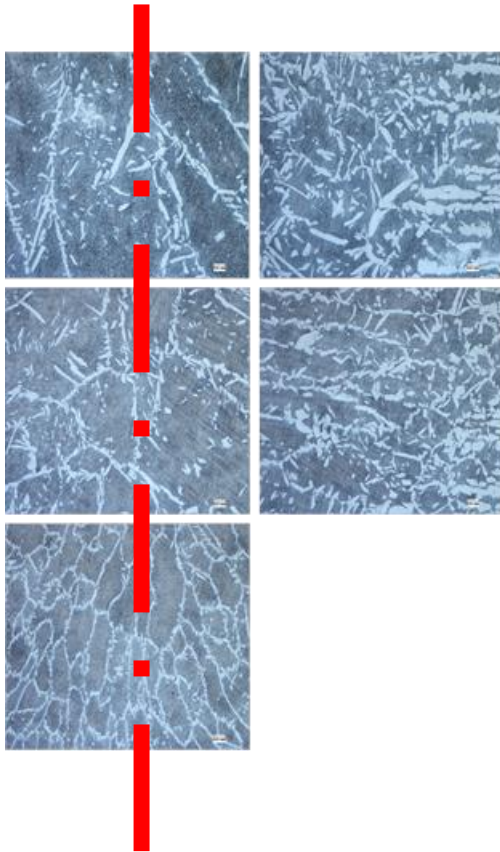
■ LBW 1.4162 Ferritescope results

Material	Weld	Ferrite-%		
		Average	WM	BM
1.4162	LBW	45.7	49.8	41.5

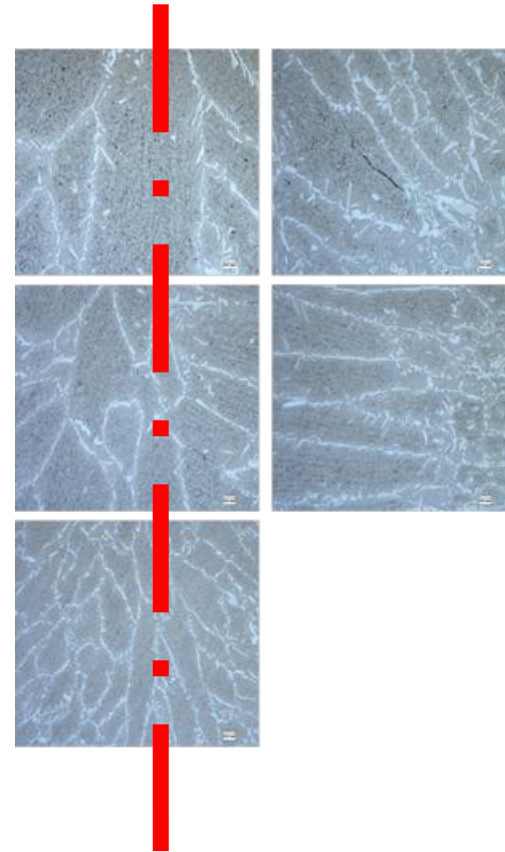


6. Microstructural characterisation

- Phase relation image analysis of 1.4162: ring laser weld



- Phase relation image analysis of 1.4162: line laser weld

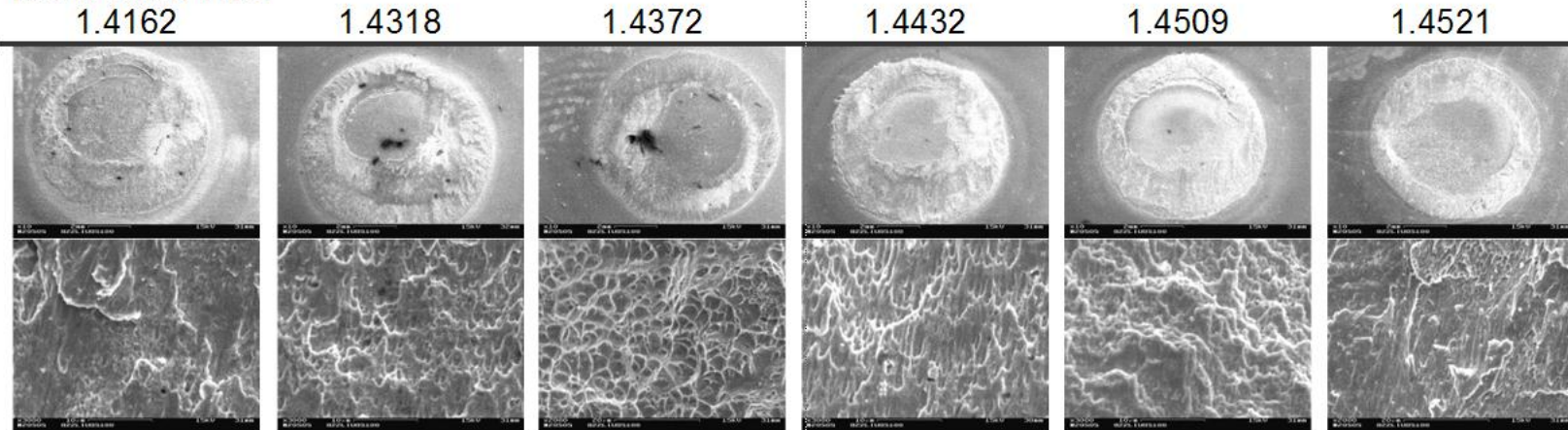


6. Microstructural characterisation

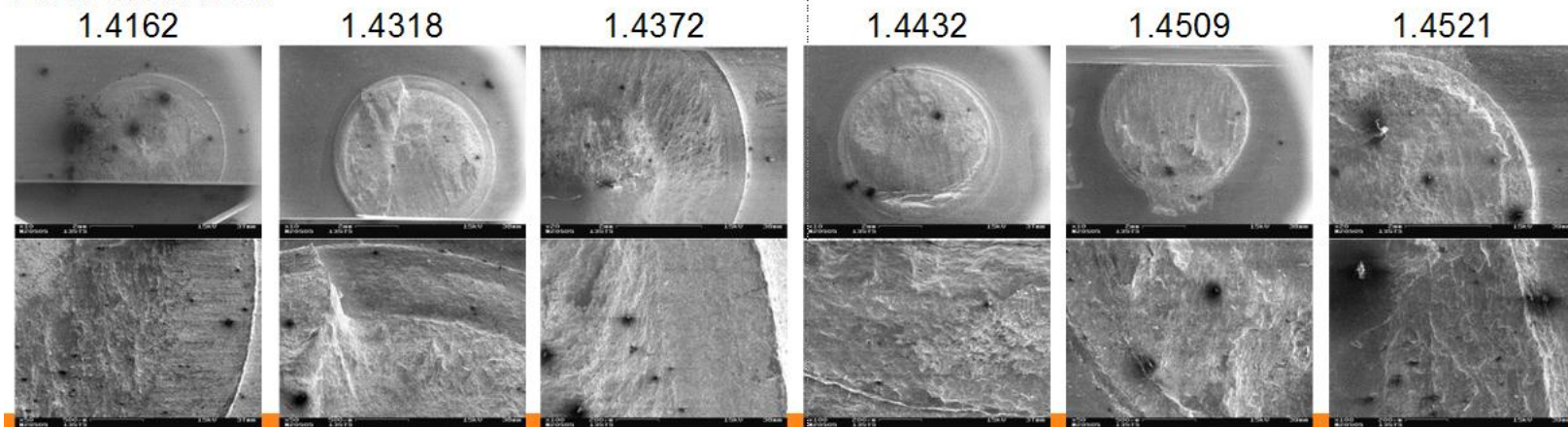
LBW circle lap	Location	Austenite concentration (%)	Ferrite concentration (%)
	Up, center	15.4	84.6
	Up, HAZ	34.8	65.2
	Center, center	16.7	83.3
	Center, HAZ	29.1	70.9
	Bottom, center	17.8	82.2
Average		22.8	77.2
LBW single line lap			
	Up,center	7.6	92.4
	Up, HAZ	16.5	83.5
	Center, center	9.9	90.1
	Center, HAZ	15.6	84.4
	Bottom, center	11.8	88.2
Average		12.3	87.7

6. Characterisation: fractography ST

Laser shear tests



RSW shear tests



6. Characterisation: fractography CT

Laser cross-tension tests

1.4162

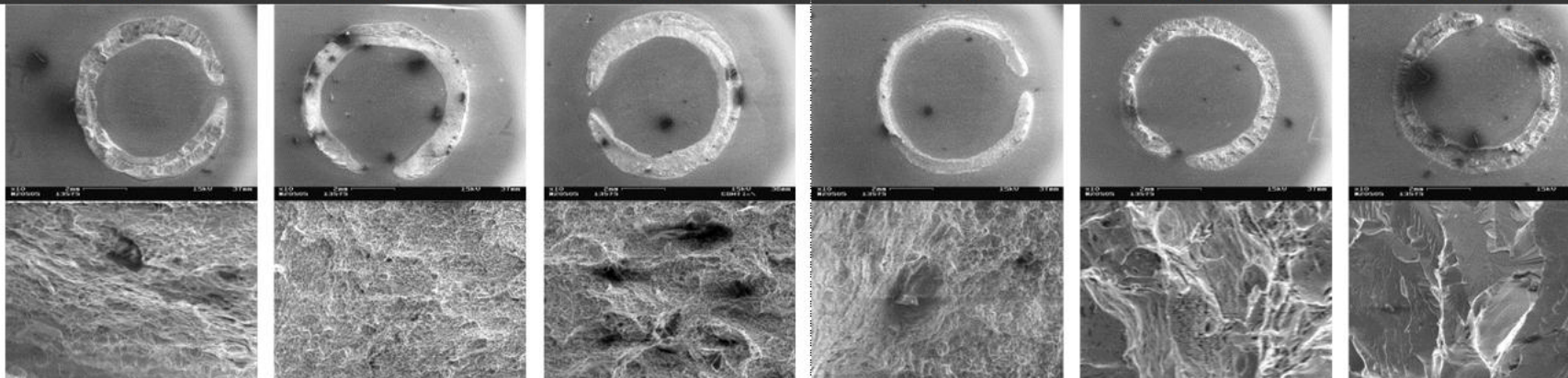
1.4318

1.4372

1.4432

1.4509

1.4521



RSW cross-tension tests

1.4162

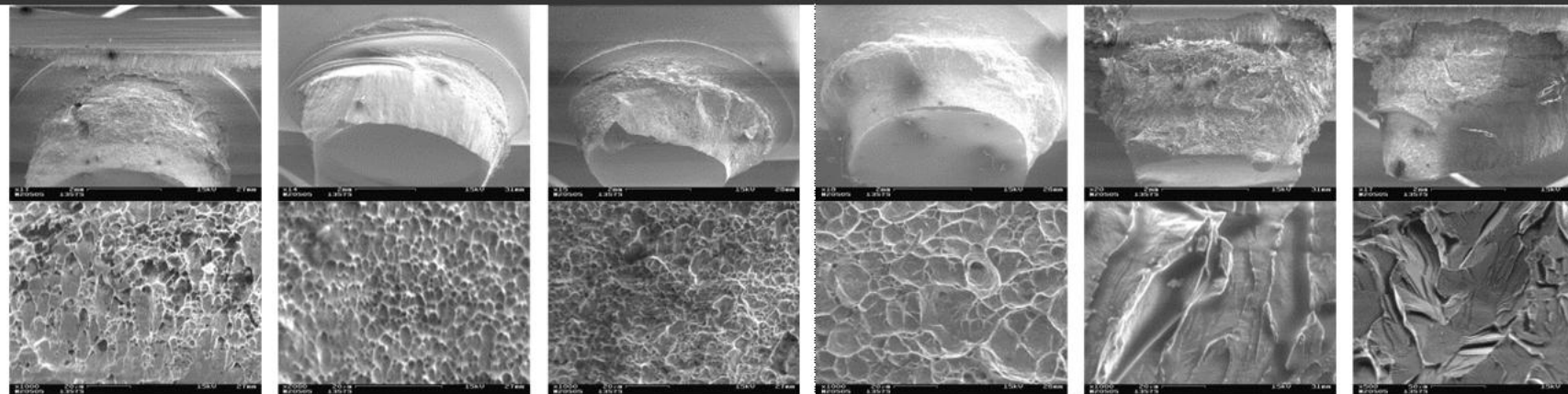
1.4318

1.4372

1.4432

1.4509

1.4521



7. Summary

Corrosion properties

- Lean duplex 1.4162 showed equal or better pitting corrosion resistance than the reference 1.4432 (316L)
- Ferritic 1.4521 shows promise but also inconsistent behaviour (scatter)
- The ASTM standard test is too severe for low-Ni austenitics 1.4318 & 1.4372 and the ferritic 1.4509
 - Further experiments in milder conditions (U) for "resolution"

Mechanical properties

- Laser butt welds showed excellent tensile properties (esp. A!)
- Circle LBW lap shear strength comparable to RSW, reduced A
- Full LBW penetration vital for cross-tension test

7. Summary (2)

Metallography and fractography

- Microstructures were as expected and as in the literature
 - Cracks or porosity were not found
 - Penetration, orientation and weld dimensions were satisfying
- Phase relations in LBW duplex stainless steel vary significantly in different parts of welds
- It is possible to improve the austenite-to-ferrite ratio with laser welding parameter optimisation
 - Ferrite concentration depends highly on cooling rate!
- SEM fractography revealed correspondence with similar base materials even when the welding method was different

8. Acknowledgements

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