Title	New generation ferritic and duplex stainless steels: Preliminary study on mechanical and in-service properties of welded joints
Author(s)	Sirén, Mika
Citation	Nordic Welding Conference 2012 (NWC2012), Oslo, 4 - 5 October 2012
Date	2012
Rights	This article may be downloaded for personal use only

Business from technology

New generation ferritic and duplex stainless steels:

Preliminary study on mechanical and in-service properties of welded joints

Mika Sirén, VTT

Nordic Welding Conference

Oslo 4 to 5 October, 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

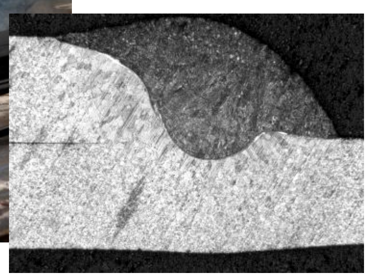
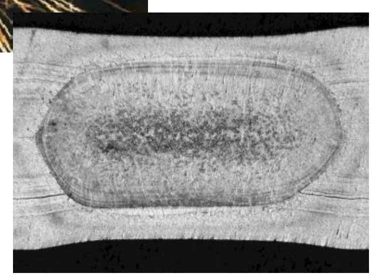
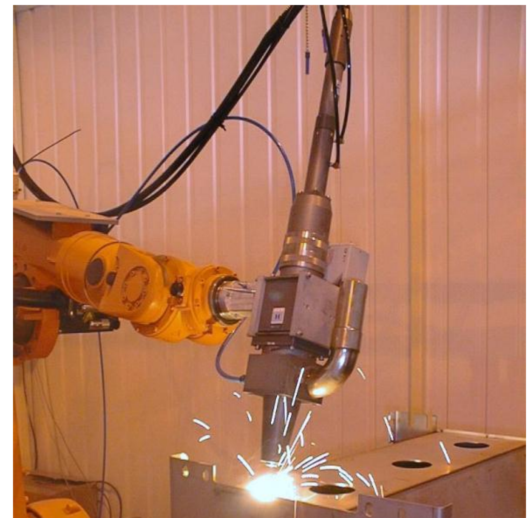
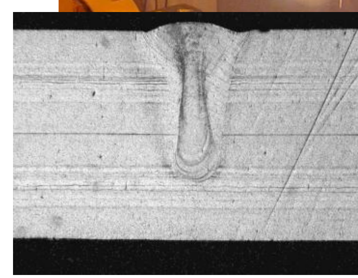
Grade EN	Type	$R_{p0.2}$ (MPa)	R_m (MPa)	Potential applications	Replacing
1.4318 X2CrNiN18-7 (2H)	Lo-Ni, Hi-N austenitic	591	922	Lesser corrosive applications, e.g. ambient service structures	Traditional Cr-Ni austenitics
1.4372 X12CrMnNiN17-7-5	Mn alloyed austenitic	428	754		
1.4509 X2CrTiNb18	Double 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)

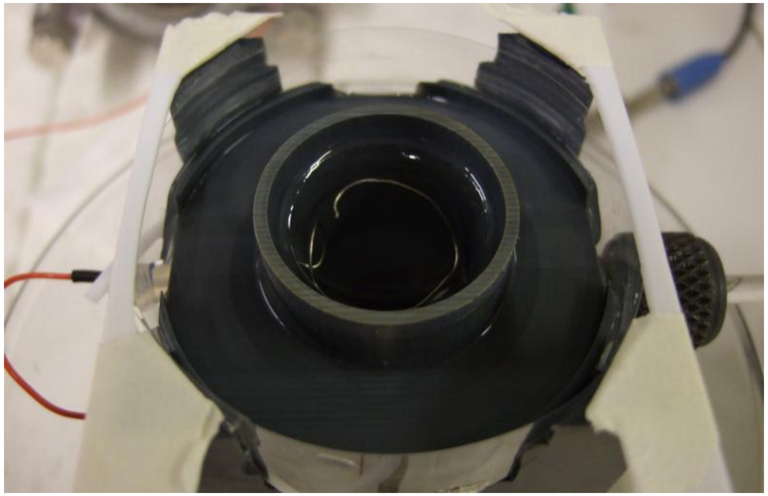


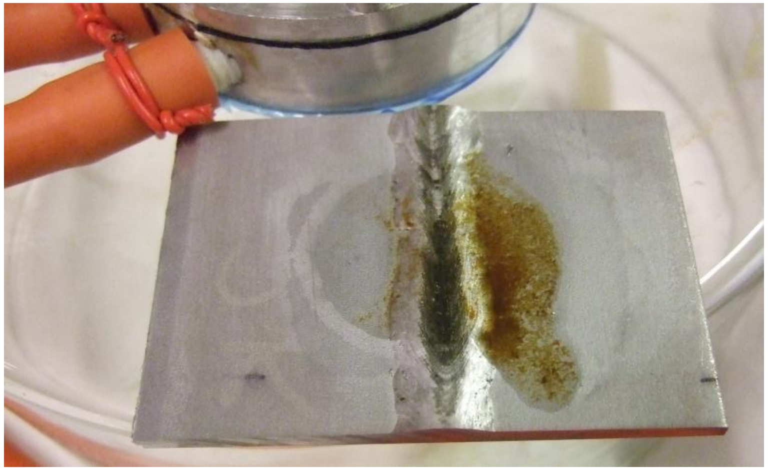





4. Corrosion behaviour

- Critical pitting temperature tests
  - Modified standard ASTM G150-99
  - Test surface area 6.6 cm^2
  - 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/cm^2





4. Corrosion behaviour

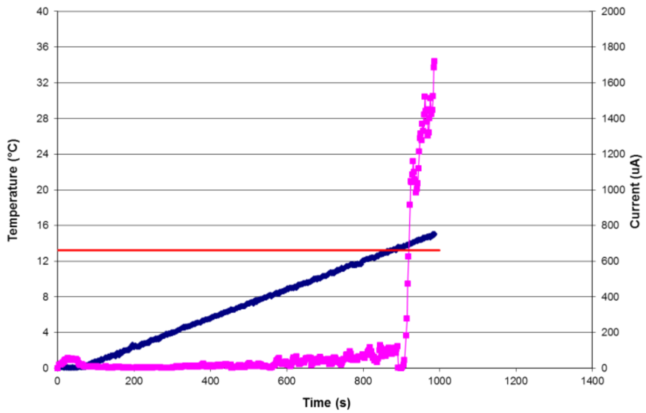
Materials	Critical pitting temperature (CPT), °C			
	Base material	LBW circle	RSW spot	MAG fillet
1.4318	12 (1.6)	< 10 (4.0)	< 10 (3.6)	< 10 (1.6)
1.4372	< 10 (3.6)	< 10 (1.9)	< 10 (2.6)	< 10 (1.8)
1.4509	< 10 (0.9)	< 10 (1.9)	< 10 (6.3)	< 10 (1.3)
1.4521	< 10 (0.8)	14 (5.3)	15 (0.8)	< 10 (1.2)
1.4162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

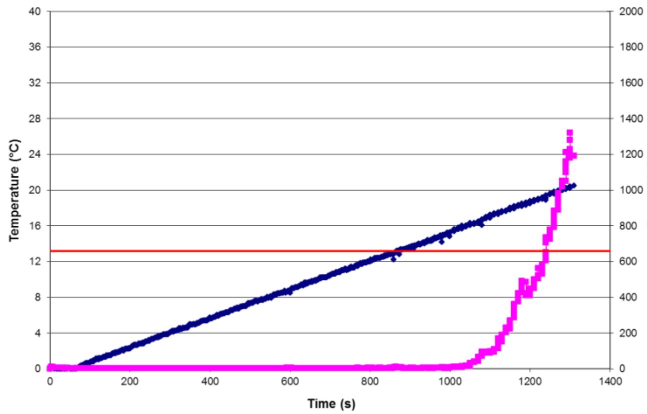
- Standard deviations in the parentheses
- All materials used as 2 mm sheet in soft 2B delivery condition except 1.4318 (2H)

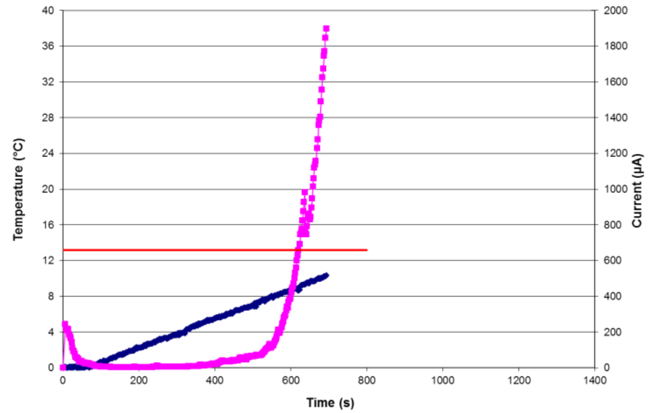
4. Corrosion behaviour

	1.4432	1.4162	1.4521

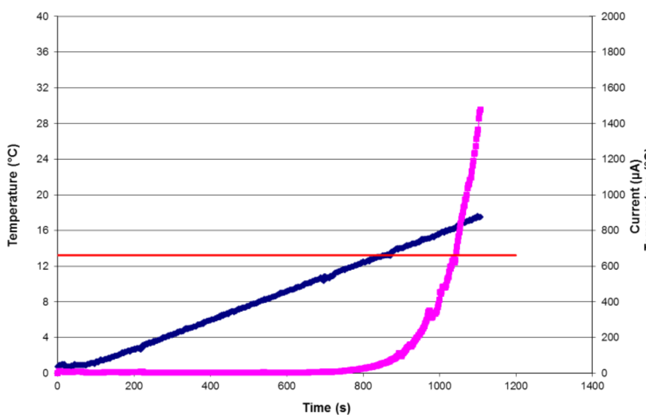
Base material

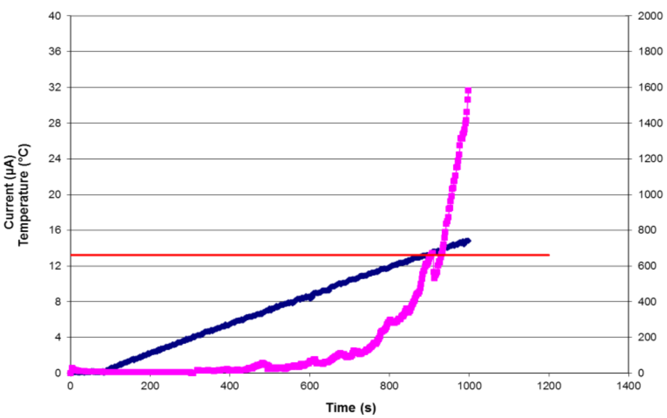


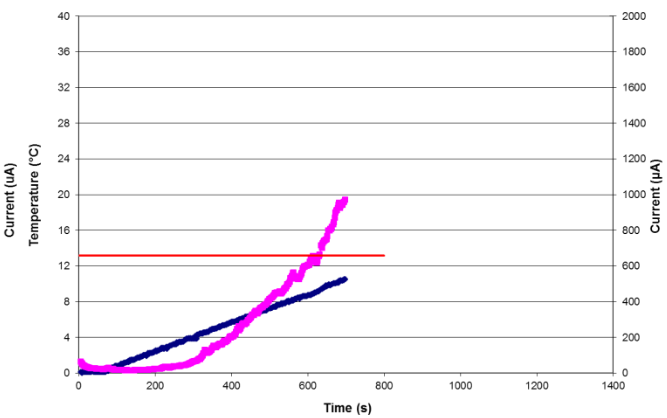




MAG weld

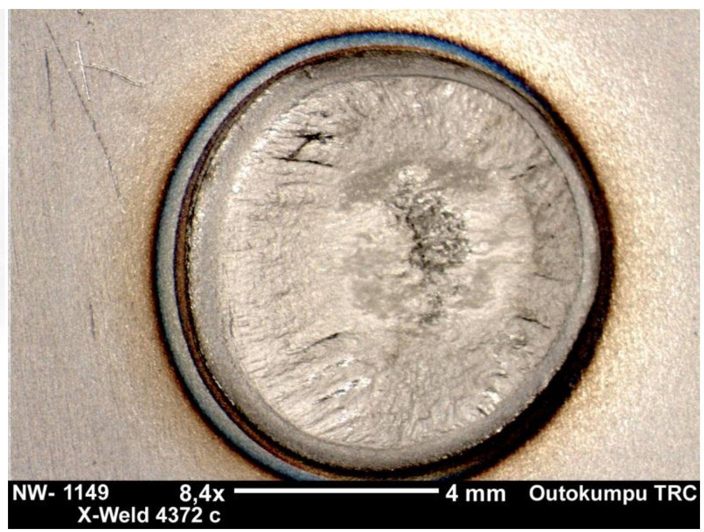






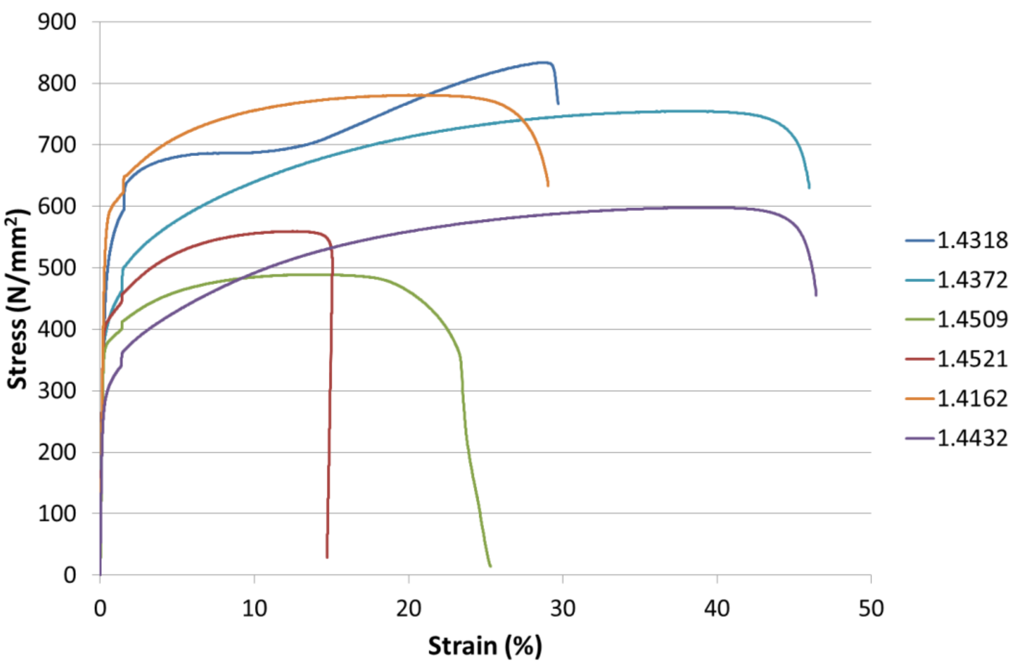
5. Mechanical behaviour

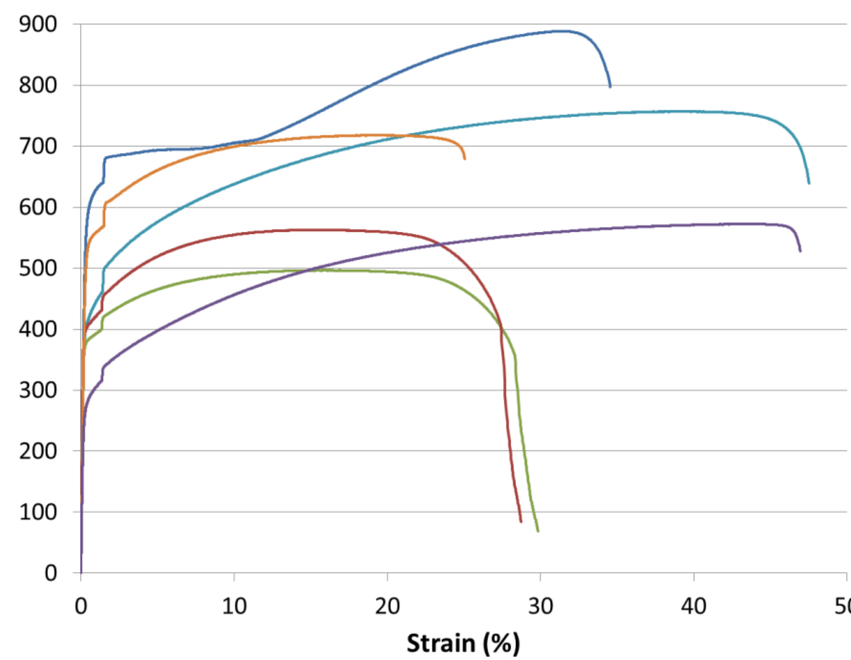
- Three types of mechanical testing
  - Transverse tensile testing for LBW & MAG butt joints (EN 895)
  - Cross-tension for circular LBW & RSW lap joints (EN ISO 14272)
  - Shear tensile for circular LBW & RSW lap joints (EN ISO 14273)



5. Mechanical behaviour: butt tensile

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





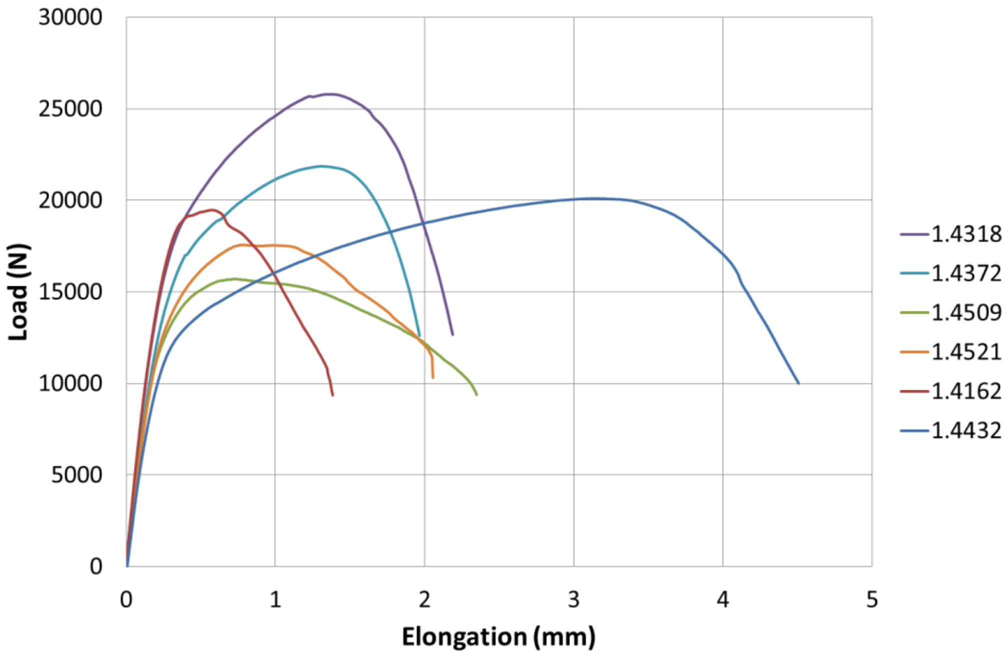
5. Mechanical behaviour: butt tensile

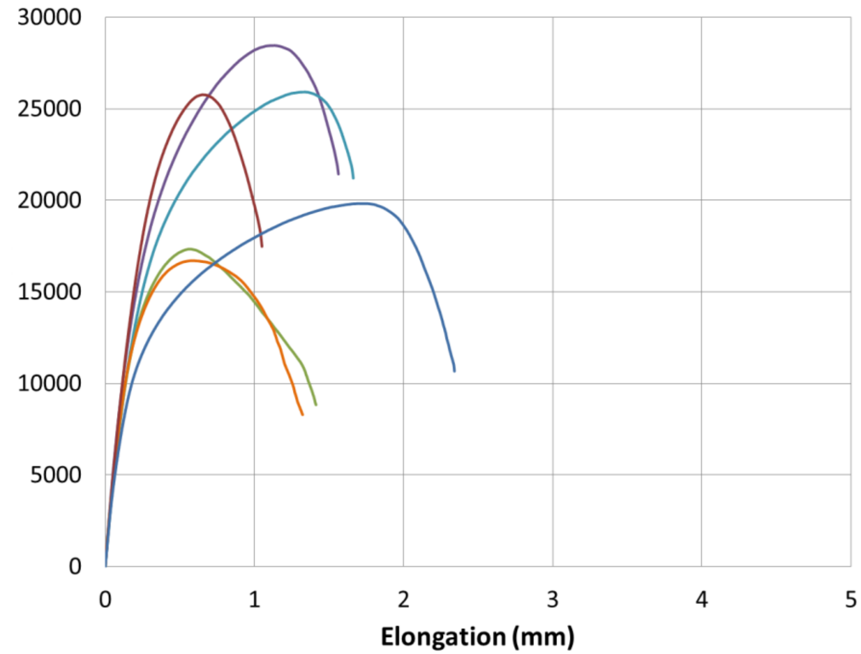
Materials		Weld	N	$R_{p0.2}$	R_m	A_{50}	Failure
Base	Filler			(N/mm²)	(N/mm²)	(%)	location
1.4318	316LSi	MAG	6	494	835	30	FL/BM
	-	LBW	4	583	892	35	HAZ
1.4372	316LSi	MAG	3	398	759	47	BM
	-	LBW	4	411	756	48	BM
1.4509	316LSi	MAG	3	374	489	25	BM
	-	LBW	4	379	496	30	BM
1.4521	316LSi	MAG	3	407	559	17	BM
	-	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

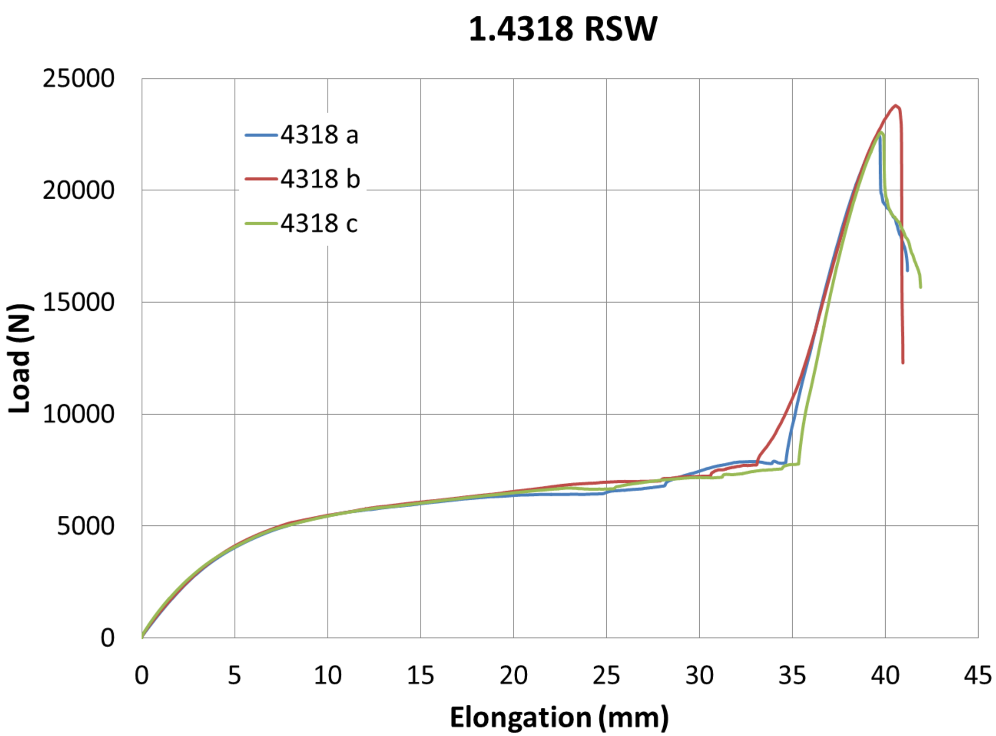
5. Mechanical behaviour: shear tensile

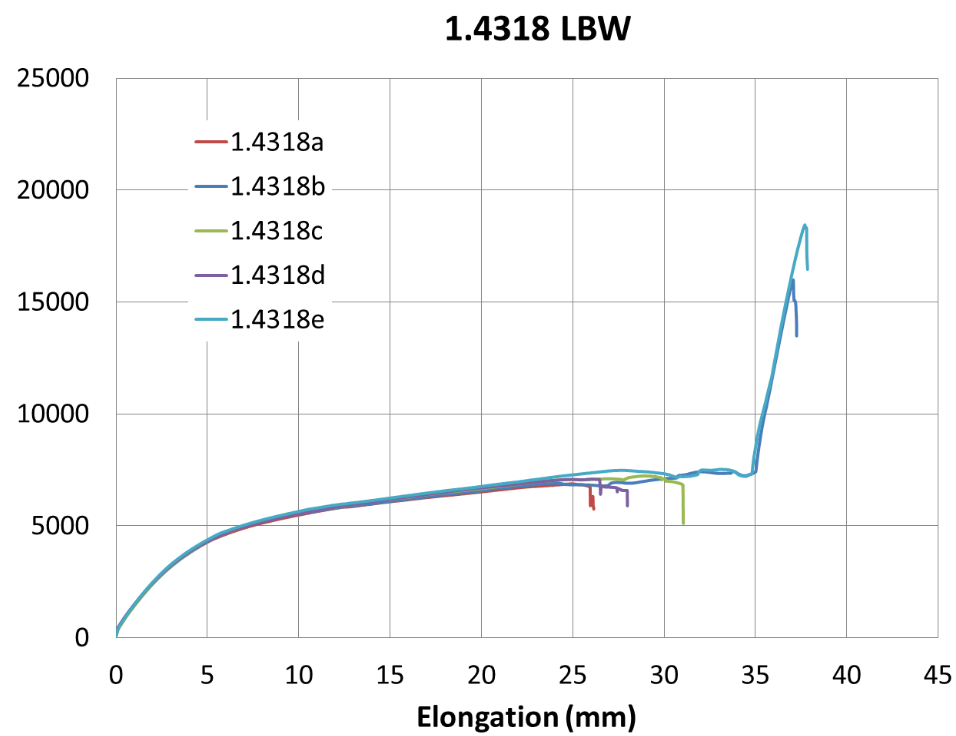
- Typical resistance spot weld
  - ø ~ 7 mm ”solid spot” weld
  - $A_{weld} \approx 38\ mm^2$
- Typical laser circle weld
  - ø 7 (o.d.) × 5 (i.d.) circle
  - $A_{weld} \approx 18\ mm^2$





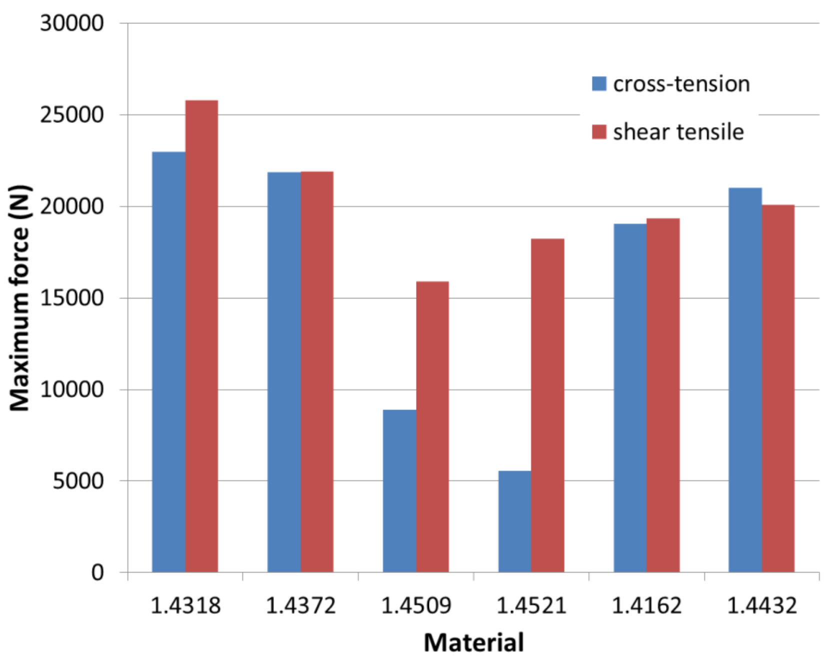
5. Mechanical behaviour: cross tension



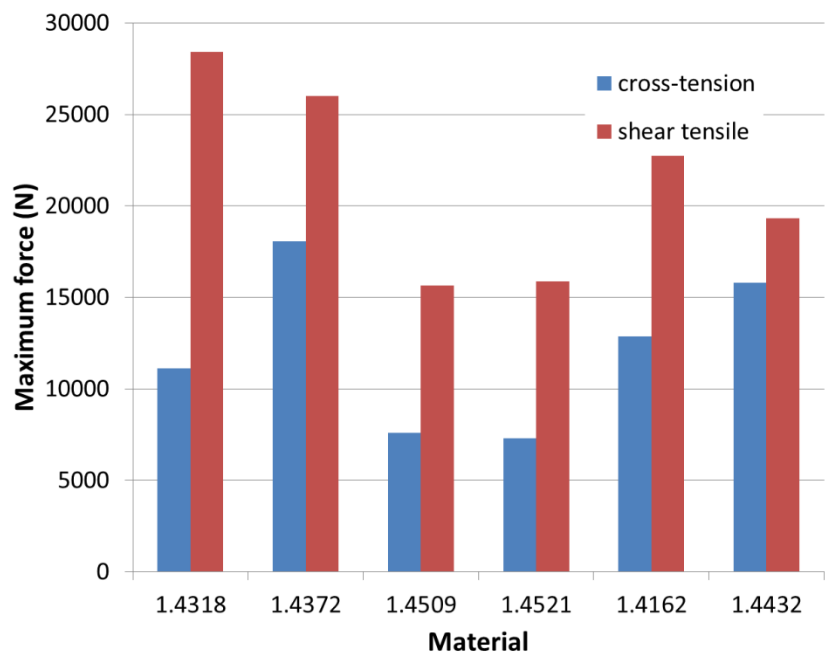


5. Mechanical behaviour: cross tension

- Cross-tension vs. shear tensile: RSW

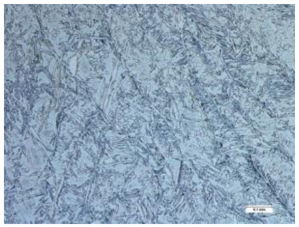
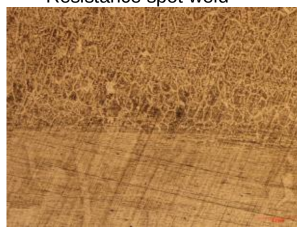


- Cross-tension vs. shear tensile: circle LBW



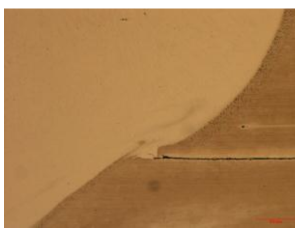
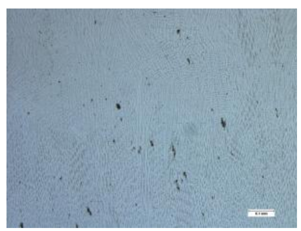
6. Microstructural characterisation

1.4162, Ring laser weld | MAG weld | Resistance spot weld

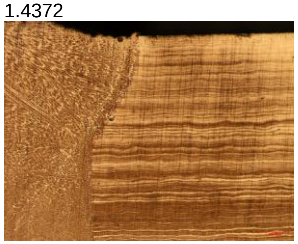




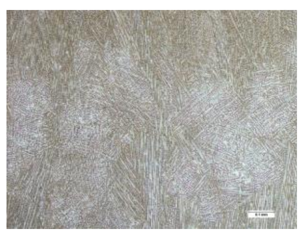
1.4162, Single straight laser weld

1.4318

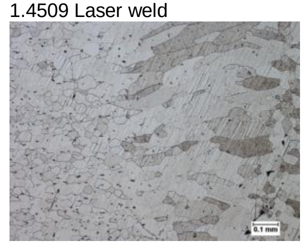
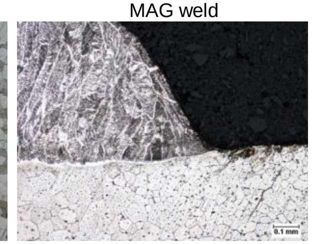




1.4372

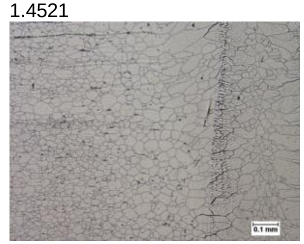


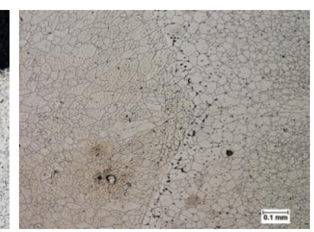


1.4509 Laser weld | MAG weld | Resistance spot weld


1.4521

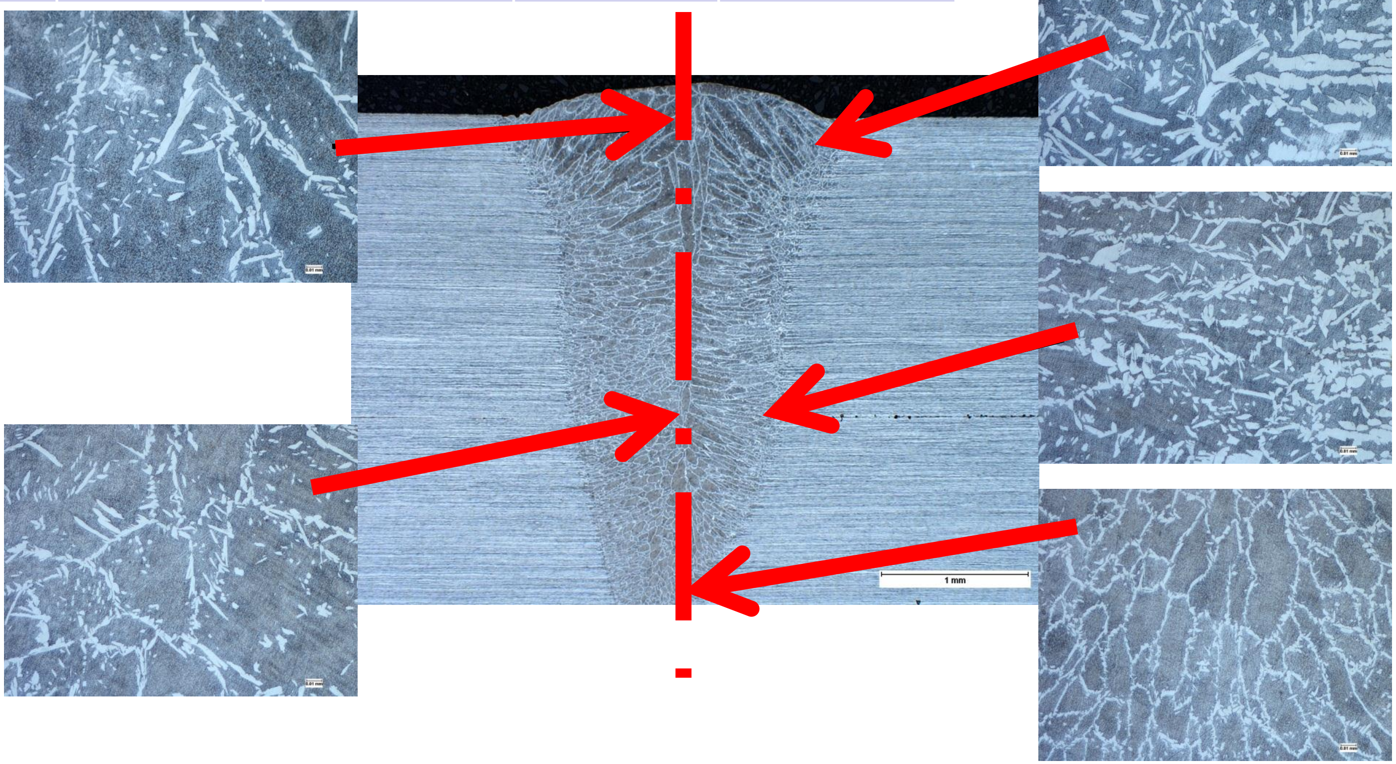




6. Microstructural characterisation

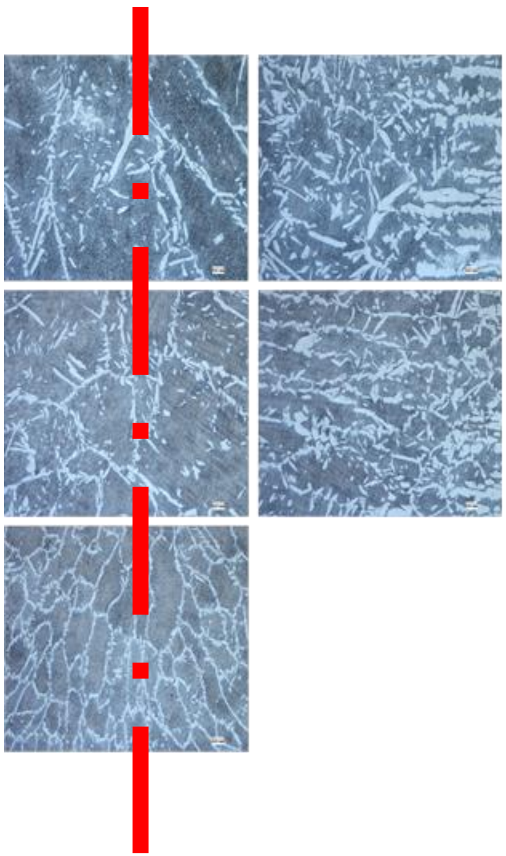
- LBW 1.4162 Ferritescope results

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

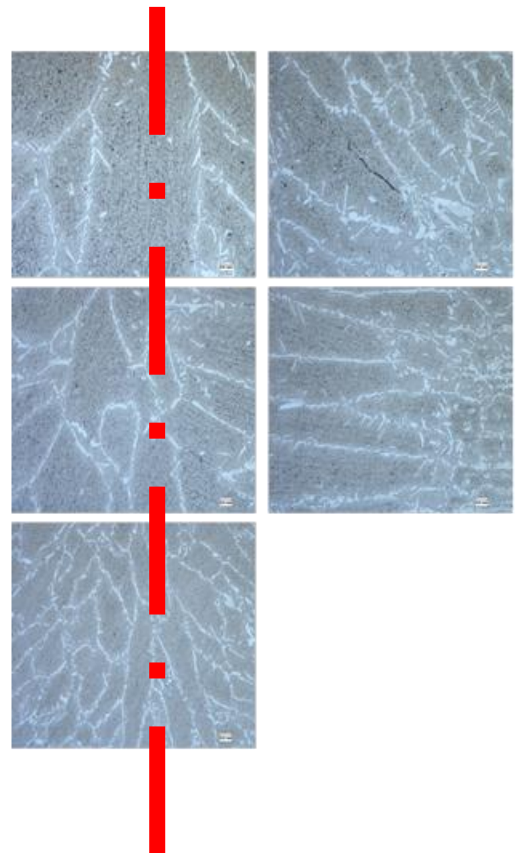


6. Microstructural characterisation

- Phase relation image analysis of 1.4162: ring laser weld



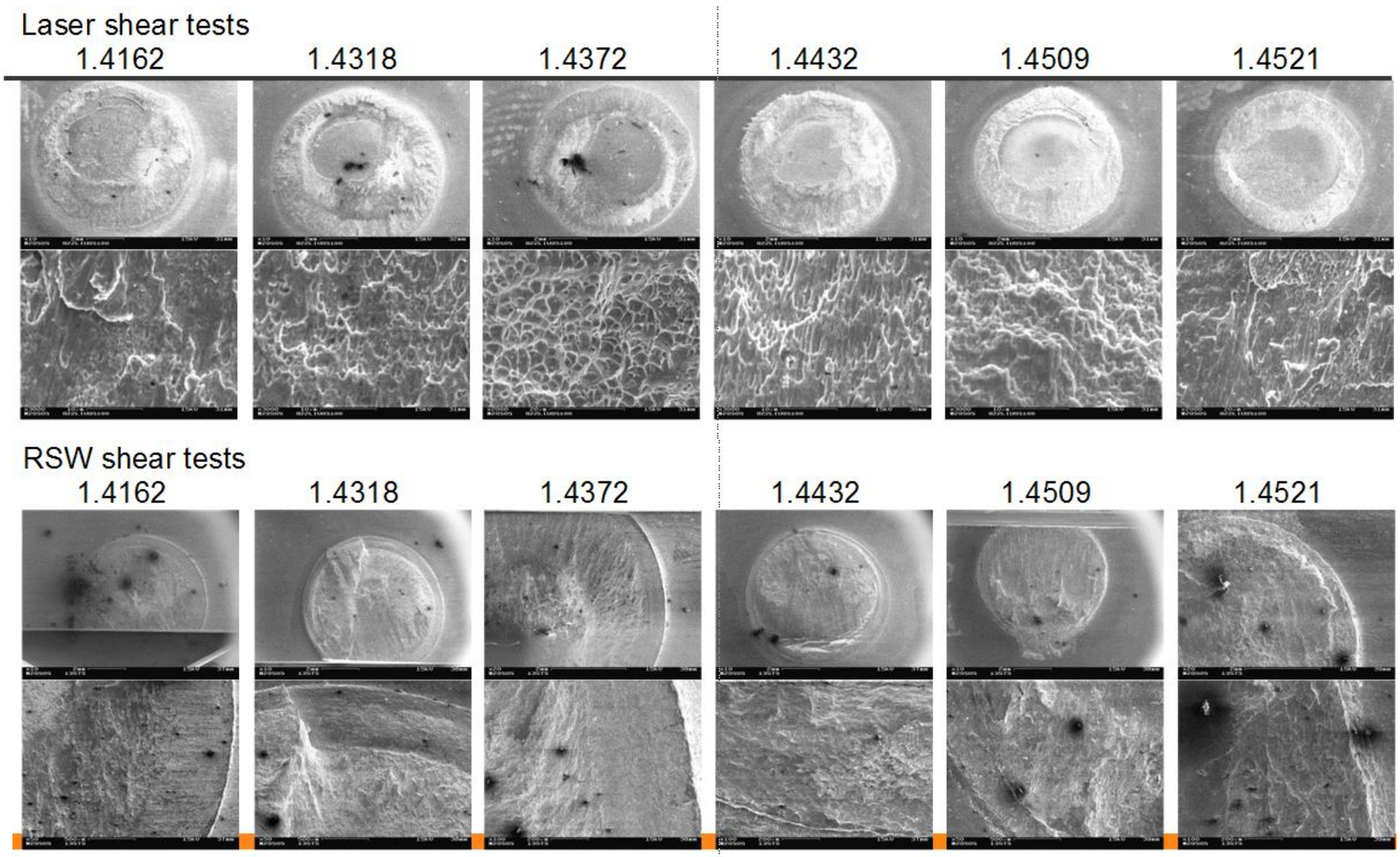
- Phase relation image analysis of 1.4162: line laser weld



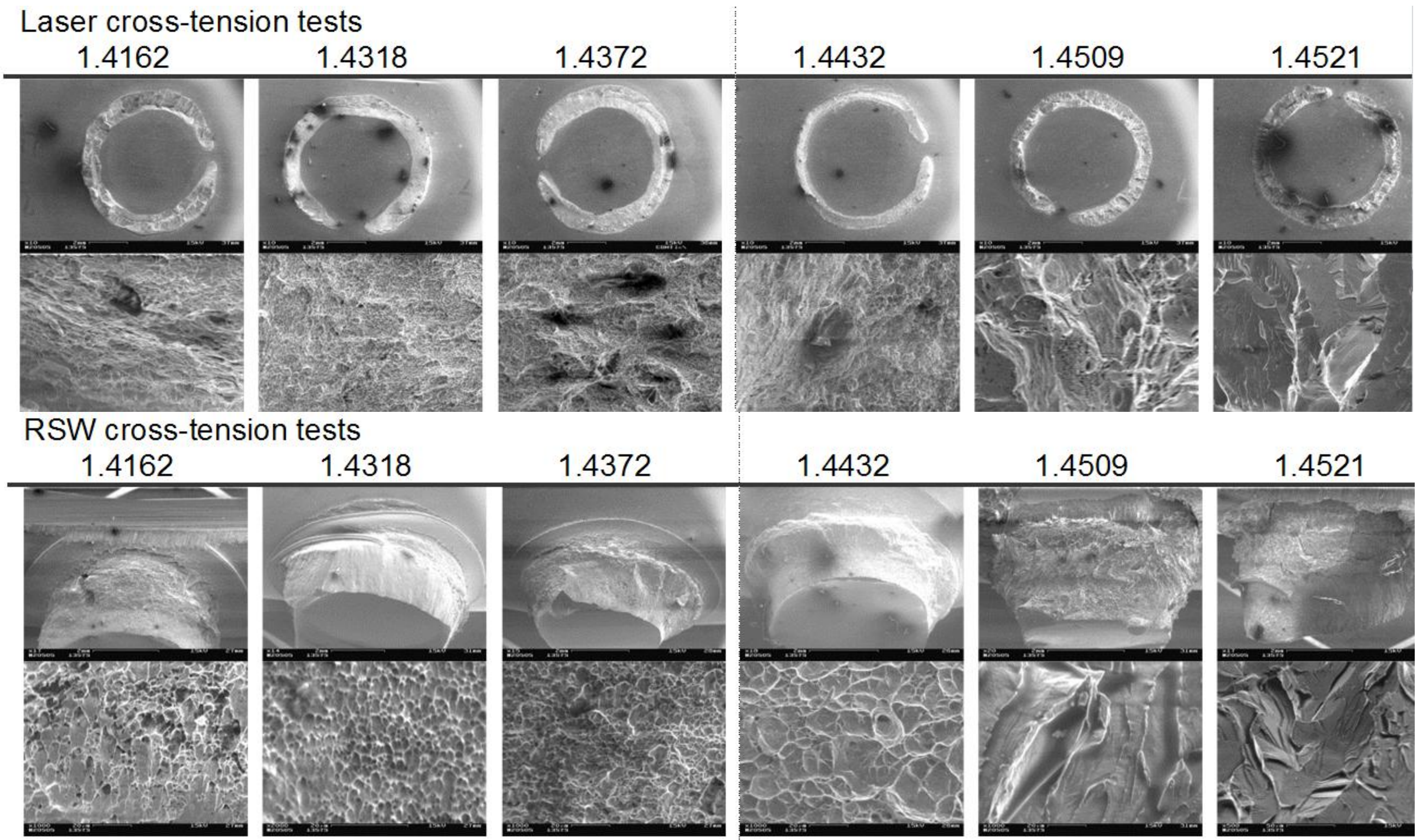
6. Microstructural characterisation

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



6. Characterisation: fractography CT



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

- Co-authors:
  - VTT Technical Research Centre of Finland
    - P. Nevasmaa, P. Varis, M. Sirén, P. Karjalainen-Roikonen, M. Karhu, V. Kujanpää
  - Aalto University, School of Engineering
    - J. Hirn*), J. Romu *)currently with SGS Fimko Oy
  - Outokumpu Stainless Oy, Tornio Research Centre
    - V. Sieppi, H-P. Heikkinen, T. Manninen, J. Säynäjäkangas
- Finance:
  - Finnish Metals and Engineering Competence Cluster (FIMECC), Strategic research theme "*Breakthrough Materials*"
    - Programme ***"Demanding Applications (DEMAPP)"*** 2009 – 2014
    - Project ***"New corrosion resistant materials and solutions"***,
    - Subproject ***"New methods to optimize the performance of welds in corrosive industrial environments (X-WELD)"*** 2010 – 2014
  - Outokumpu Stainless Oy, Andritz Oy
  - Tekes – the Finnish Funding Agency for Technology and Innovation

VTT – 70 years of

Technology for business and society