ROESTVRIJ STAAL IN CRYOGENE TOEPASSINGEN

Inhoud

- Toepassingen
- Eisen aan de kerftaaiheid
- Ferriet in lasmetaal
- Verschillende lasprocessen
- Massieve draden
- Bedekte elektroden
- Gevulde draden
- Controle over essentiële ontwerpvariabelen
- -Chemische samenstelling
- -Ferriet gehalte
- Effect van lasprocedures
- Samenvatting

Impact toughness requirements

- The impact toughness test is usually carried out at -196°C using liquid nitrogen despite the fact that the design temperature is often at a higher temperature
- Usual requirements: 15mils (0.38mm) lateral expansion (ASME B31.3) & CVN >27J.
- European requirements (TÜV) min 32J CVN
- Customer specific requirements can be higher (60J)
- ASME / API…..ferrite in weld metal min 3FN or 5 FN or…

Impact toughness requirements

- Useful toughness can also be maintained down to liquid helium temperatures -269°C (4K) for superconducting applications.
- Impact testing procedures at this temperature are complex and expensive, with results of questionable validity.
- To qualify the toughness of weld metal for service at 4°K, the ASME Code Committee has proposed (21mils) at –196°C (77°K).
- This proposal is based on correlations between fracture toughness and Charpy data at these temperatures.

Ferrite in weld metal

- What is ferrite
- How is ferrite formed
- How can we measure or determine ferrite
- The accuracy of measuring or determining ferrite
- Conclusion

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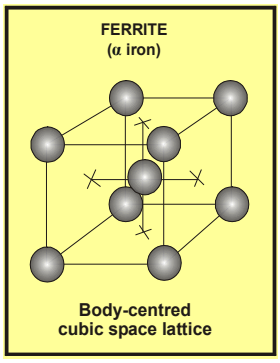
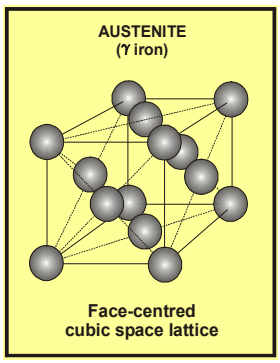
What is ferrite?





= Fe + Cr + Mo + Ti + Nb + Al + Si
Ferrite formers

= Fe + Ni + Mn + N + Cu
Austenite formers

α ferrite (<600°C) & δ ferrite (>600°C)

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What is ferrite?

Essential part within the family of stainless steel type

- Ferritic Cr - (17 x C) > 12.5
- Martensitic Cr - (17 x C) < 12.5
- Austenitic (with x % ferrite)
- Fully Austenitic
- Duplex & Super duplex
- Precipitation Hardening “PH-types”

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What is ferrite?

- Ferrite is at least important enough as there are many specification

- Because depending on the volume of ferrite it can cause;
  - Sufficient assurance to avoid when welding dissimilar joint
  - Embrittlement due to prolonged exposure to high service temperatures
  - Embrittlement due to exposure to cryogenic temperatures
  - Providing increased strength and providing special corrosion properties in Duplex & Superduplex

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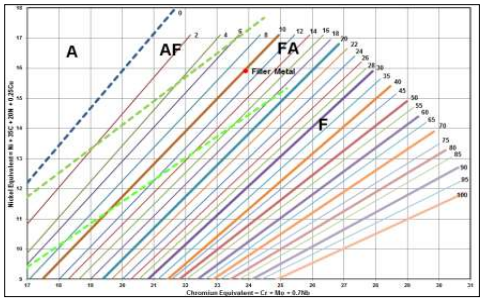
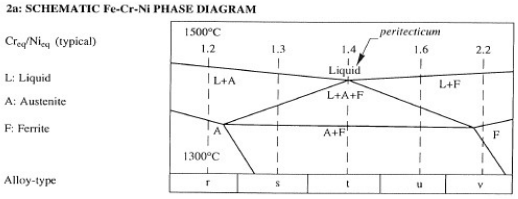
How does ferrite form in stainless steel

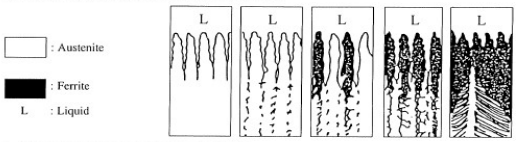


Alloy	C	Cr	Ni	Mo	N	Creq/Nieq
308L	0,02	19,5	9,7	0	0,06	1,7
316L	0,02	18	11,5	2,8	0,06	1,6
2209	0,02	22	9,5	3,1	0,16	1,9
310	0,12	26	20,5	0	0,06	1,0

2a: SCHEMATIC Fe-Cr-Ni PHASE DIAGRAM



2b: CRISTALLISATION and TRANSFORMATION



2c: STRUCTURE FORMATION SEQUENCE

Solidification	L L+A - A	L L+A L+A+F A+F	L L+A+F - A+F	L L+F L+A+F A+F	L L+F - F
Solid state evolution		F: reduction	F: reduction	F: reduction	A: formation
Structure at R.T.	A	A+F	A+F	A+F	F+A

2d: STRUCTURE at ROOMTEMPERATURE

Second phase at R.T. Sec. phase morphology	no -	F rounded rod-like	F vermicular rod-like	F vermicular	A Lathy Widman- stätten
Ferrite number (typical)	0	1	2.5	7	50

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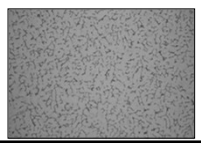
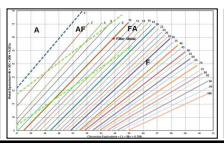
How can we measure or determine ferrite

Type	Methode
Permeabiliteit	Fischer Permascope
	Förster
Metallographic	Point counting
	Reference books
	Electronical analysis
Chemical composition	Schaeffler
	DeLong
	WRC92
Magnetisme	Magne Gage





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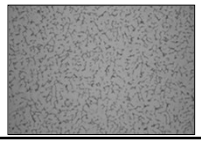
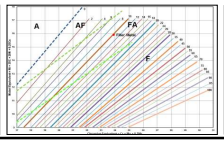

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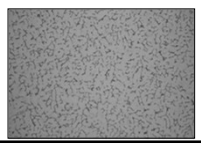
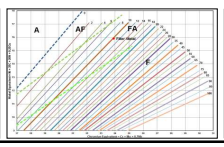
How can we measure or determine ferrite

Type	Method	Unit
Permeabiliteit	Fischer Permascope	FN & %
Metallographic	Point counting	%
Chemical composition		
	WRC92	FN
Magnetisme	Magne Gage	FN

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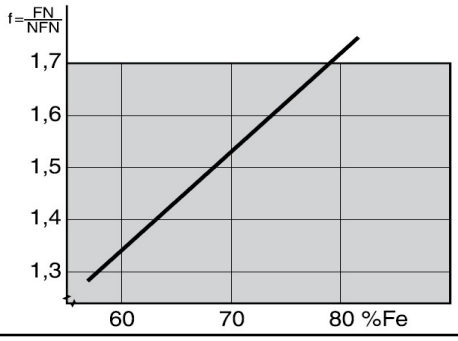
How can we measure or determine ferrite

- In principle ; Ferrite Number ≠ % Ferrite
- The correlation is depending on the %Fe in an alloy
- At low ferrite values (<10) FN ≈ %Ferrite



The accuracy of measuring or determining ferrite

- Recognizing the variables when measuring ferrite is crucial!
- Round robins : lab-to-lab variation!
- Sample preparation
- Etching of the sample
- Procedural effects (cooling speed of weld metal)
- Burn-off of elements (Cr)
- Pick-up of elements (N)
- etc

ASTM E562 Point Counting

Variables
- Etching
- Magnification
- Number of measurements

Area	Average	Deviation
Parent material	56	+/- 4
HAZ	54	+/- 18
Cap weld metal	61	+/-8
Center weld	36	+/- 11

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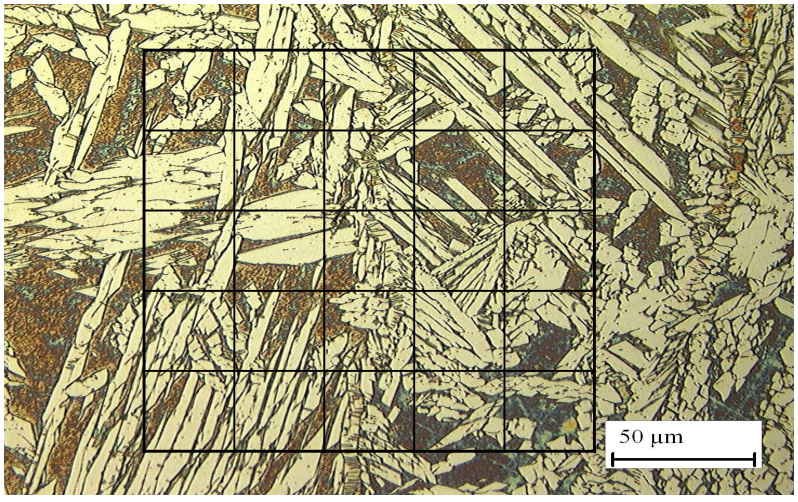
Point Counting magnification 400X



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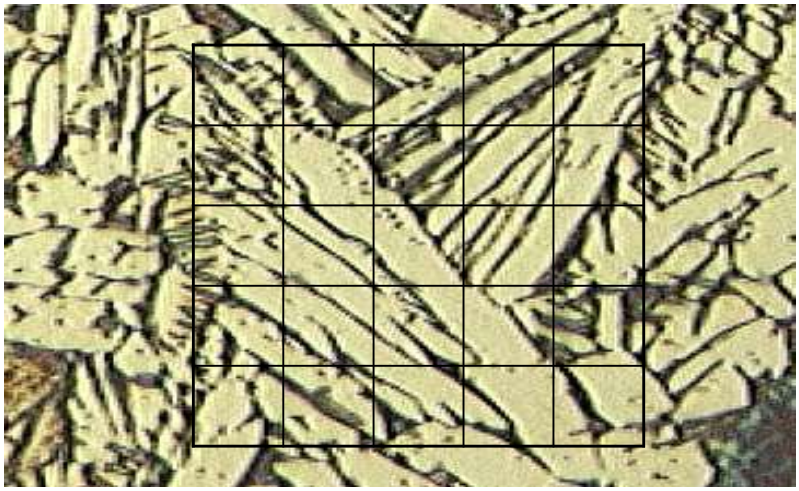
Point Counting magnification OK?



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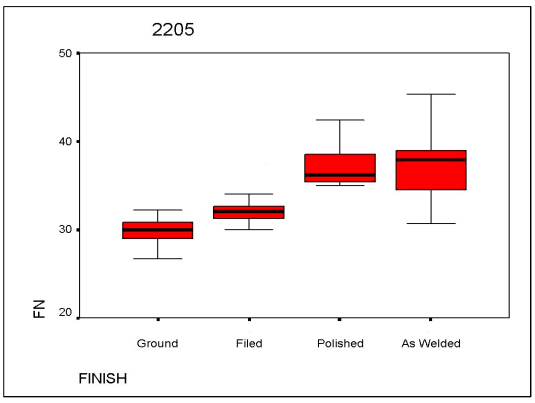
Ferrite Number (Ferritescope / Magne gage)

Variables:

- Finishing
- Number of measurements
- Lifting speed (Magne gage)



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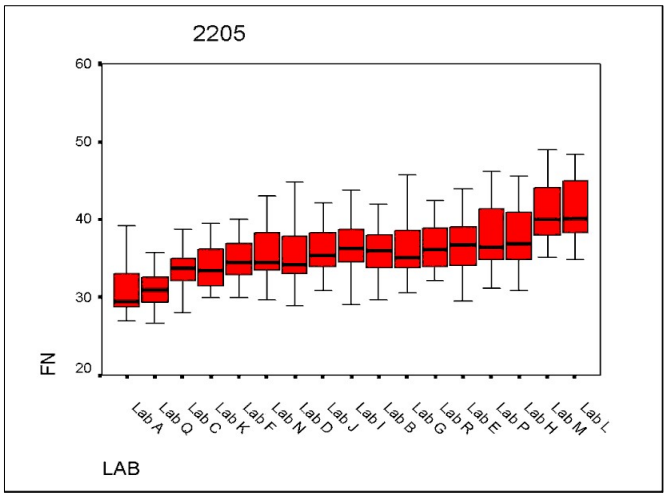
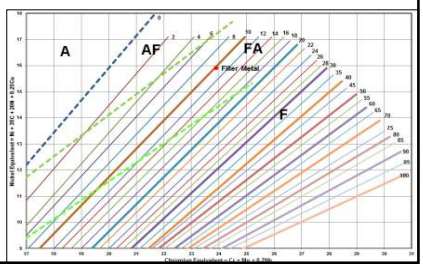
Ferrite Number (Ferritescope / Magne gage)



Ferrite Number WRC92

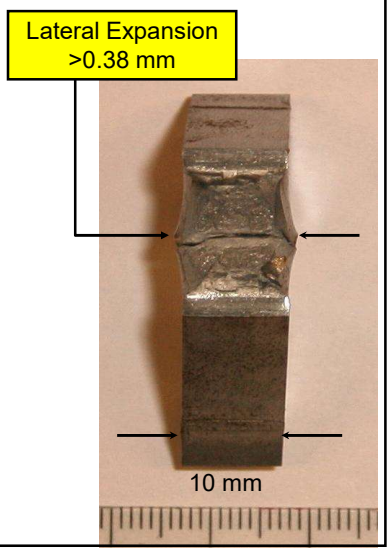
- Measuring method of the chemical analysis (accuracy)
- Type of consumables
  - Solid wire; analysis wire
  - Process with slag system : deposited analysis
- With of without Nitrogen in the analysis
- Relation between ferrite in all weld metal and in a joint?
  - Welding process
  - Welding parameters
  - Polarity
  - Gas type
  - Arc length
  - Cooling speed
  - Dilution



Conclusion

- Ferrite in a metallic structure?
  - Magnetic
  - Can have different properties depending on the volume
- Multiple measurement methods are available that need to be applied using proper knowledge
- Units
  - Percent ferrite
  - Ferrite Number
  - Up to 10 FN ≈ % Ferrite

Impact toughness requirements



Welding Processes GTAW - GMAW

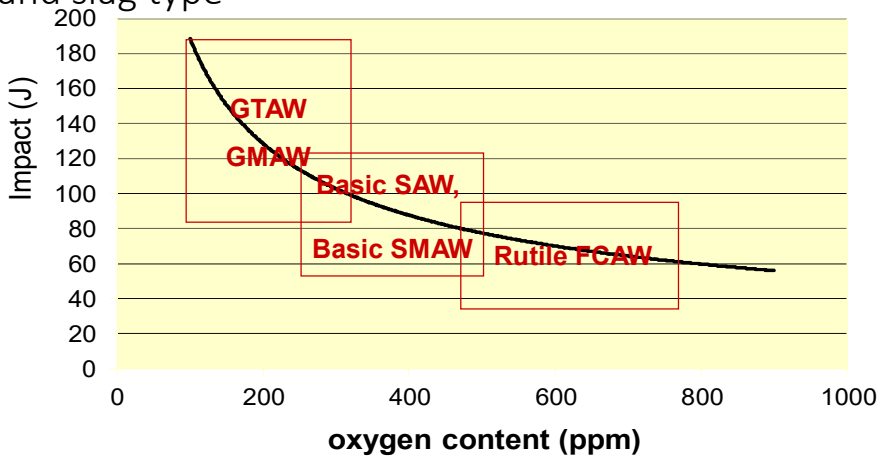
- Standard solid wire welding processes typically provide sufficient impact toughness -196°C over a range of ferrite contents
- GTAW (308L/LSi-316L/LSi) all weld metal test results typically vary : 50-100J CVN and LE~ 1.0mm
- GMAW (308LSi/316LSi) all weld metal tests results ($Ar\text{-}2\%CO_2$) vary : 35-55J en LE~ 0.5mm
- GTAW (ER316LMn) >>0.53mm @ -196°C
- Standard solid wires meet the current mechanical requirements found in the industry

Welding Processes GTAW - GMAW

Product	Diameter	Lotnumber	CVN @ -196°C [J]	Ind values [J]			Remarks	FN [WRC-92]
ER308LSi	2.4mm	55525137	98	97	99	98		9
ER308L	1.6mm	809220	53	58	53	47	LE 0,71-0,67-0,58	13
ER308L	2.4mm	5553961	67	70	66	66	LE 1,01-0,96-0,90 HV10: 184	8
ER308L	3.2mm	5553872	79	80	80	77	LE 1,07-0,99-0,94	11
ER308L	2.4mm	55537648	68	69	66	68		10 Delong
ER308LSi	2.4mm	8010266	63	60	62	67		
ER308L	2.4mm	30219825	71	68	78	68	LE 0,97-0,90-0,85 HV10: 187	4

Product	Diameter	Lotnumber	CVN @ -196°C [J]	Ind values [J]			Remarks	FN [WRC-92]
ER316L	2.4mm	55312113	87	93	83	86		7
ER316L	2,4mm	59340004	84	86	85	80	LE : 1,00 - 1,08 - 0,80mm	7
ER316L	1,6mm	55527214	89	86	96	85		
ER316L	2,4mm	55523886	87	66	106	89		
ER316L	1,2mm	55520948	75	70	80	75	LE: 0,99 - 1,16 - 1,07mm	
ER316L	2,4mm	55208091	90	92	88	91	LE: 1,05 - 1,22 - 1,18mm	8

Impact toughness as a function of welding process and slag type



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Welding Processes: SMAW-FCAW

- Welding processes with a slag system SMAW-FCAW-SAW do not produce adequate toughness unless specifically developed
- Wire/Flux combinations need to be carefully selected
- The majority of the standard electrodes provide insufficient toughness at -196°C
- Specifically developed consumables are required to consistently meet >0.38mm LE / 27J at -196°C

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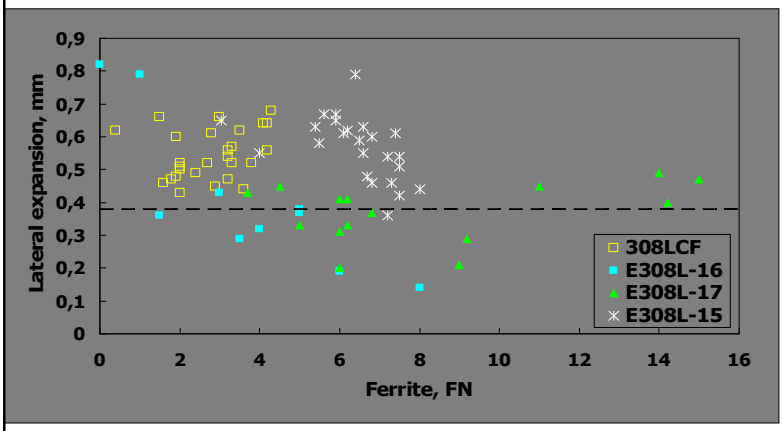
Welding Processes: SMAW-FCAW

- Development of 308L-316L consumables for >0.38mm LE / 27J at -196°C focusses on 3 areas
  - Ferrite content in weld metal
  - Chemical composition
  - Mineral raw materials

Controlling the ferrite content

- Various international standards provide limits for ferrite in weld metal:
  - ASME III : 5FN minimum (3-10FN >800°F / 426°C).
  - API RP 582 : 3 FN minimum, with comment, for cryogenic service lower FN may be required".
- *Controlled Ferrite* 'CF' consumables in the range of 2-5FN.

Effect of ferrite SMAW 308LCF



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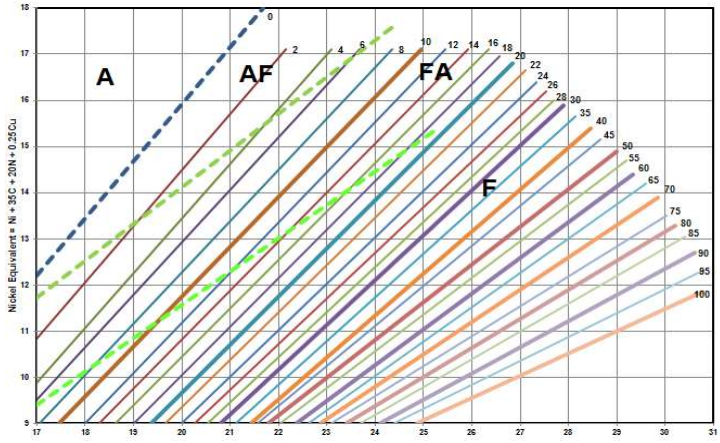
Controlled Ferrite

- Solidification structure plays a role!



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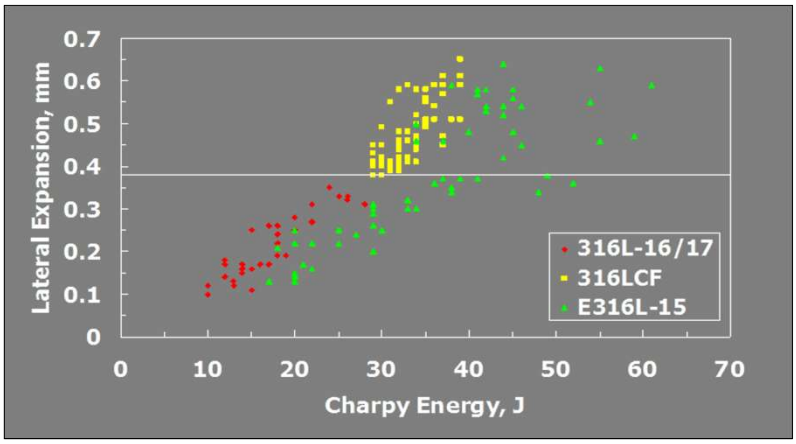
SMAW 316L CVN-LE correlation

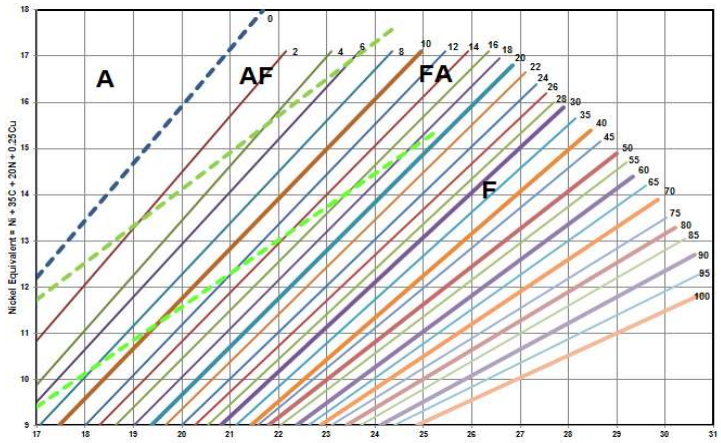


Controlled Ferrite

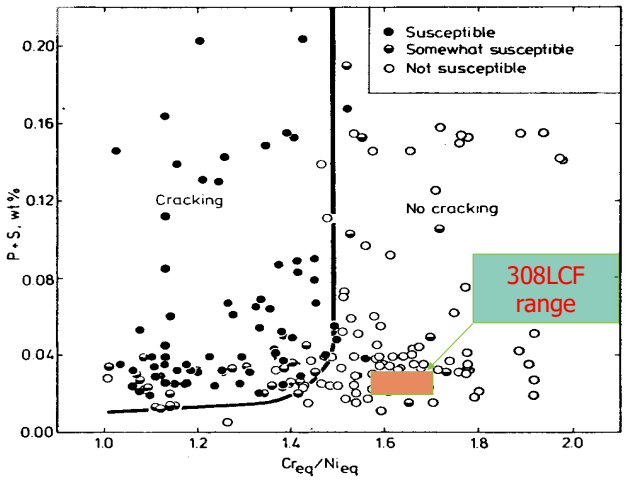
- Minimum ferrite levels are required to avoid possibility of hot cracking
- There are sometimes discussions on low ferrite values (~2FN).
- It is possible, even with low ferrite values, to have the preferred ferritic-austenitic solidification mode by controlling the Cr/Ni ratio
- The have been no reports of hot cracks in the history of Metrode 308LCF / 316LCF range

Controlled Ferrite

- Solidification structure plays a role!



Suutala diagram - 308LCF



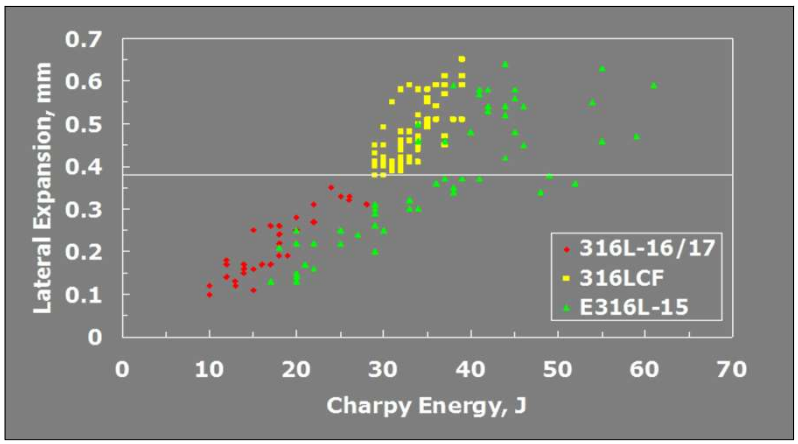
Gecontroleerde samenstelling

- A balanced composition is required to produce in the desired ferrite range
- Total %Cr + Mo.
  -More critical with 316L than with 308L.
- SMAW & FCAW : Mo range 2.0-2.5%.
  -SMAW 308L: AWS + EN-ISO
  -SMAW 316L: AWS only (EN-ISO min 2,5%)

SMAW covering

- Even with fully basic electrode coverings it is required to control the ferrite level and chemical composition
- Controlling ferrite and composition is essential in combination with basic-rutile electrode coverings
- Both basic and basic-rutile electrode types are suitable for pipe welding

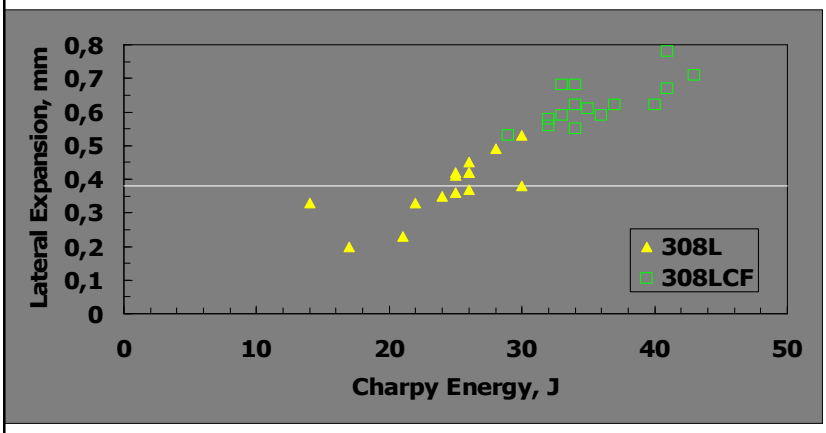
Effect of SMAW covering



Flux cored wire

- Cored wires are fast freezing rutile cored due to the main application : pipe welding – positional welding
- E308LT1-4 & E316LT1-4.
- Same composition range as SMAW
- Same ferrite ranges as SMAW; 2-5FN

Flux cored wire – 308L -196°C toughness



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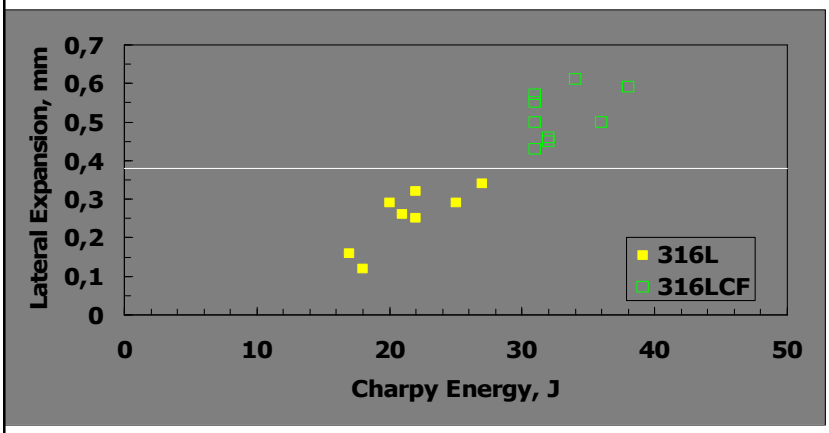
Flux cored wire – 316L -196°C toughness



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Effect of the welding procedure

- The strength properties of austenitic stainless steel is only limitedly influenced by the welding procedure
- There is a clear HI-toughness correlation with the SAW process
- Same effect is visible with the SMAW process but less pronounced
- High HI does not have a negative effect in cryogenic applications

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Procedure effects SAW -196°C

SAW in 22mm plate; same batch wire flux in all plates
ER316L – P2007
U & I constant, v variable

Heat input kJ/mm	Runs	CVN J	Lateral expansion mm	Ferrite FN	Cr+Mo %
1,0	27	28	0.30	5	21.3
1,8	17	34	0.43	7	21.3
2,8	10	46	0.48	7	21.0

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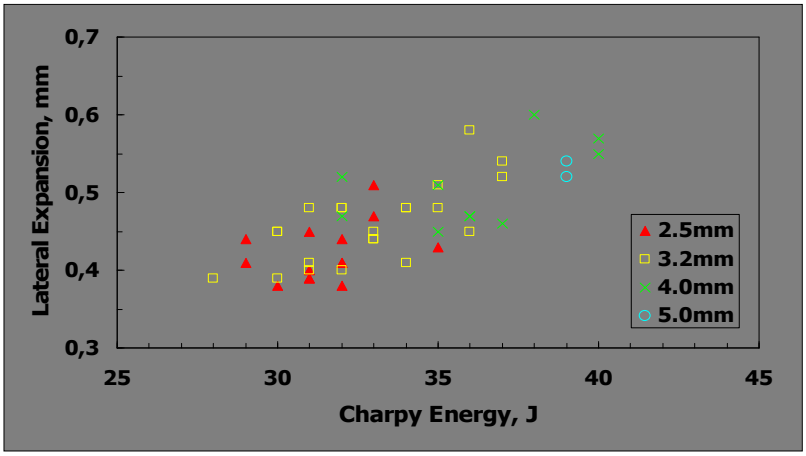
Procedure effects SMAW -196°C



Summary

- Gas shielded welding processes using solid wires provide good impact toughness at -196°C due to low oxygen and low inclusion content in weld metal
- Welding processes with a slag system can provide good toughness provided that the composition/ferrite are properly controlled
- Both E308L-15/-16 & E316L-15/-16 SMAW with controlled composition/ferrite can meet >27J/0.38mm LE requirements
- Ferrite in the range of 2-5FN has not caused hot cracking issues.