INTERNATIONAL WORKSHOP ON

FABRICATION & PROCESSING OF GRADE 91 MATERIAL

FAB 91

25 – 26 February 2011
Tiruchirappalli
INDIA

Organised by

WRI BHEL IIM

PROGRAMME SCHEDULE

February 25, 2011

SESSION 1	GRADE 91 MATERIALS – TUBES, PIPES	
	Introduction to Grade91, Applications of Grade 91, chemical composition, mechanical and creep properties, long term micro-structural evolution	**Mr. Stefano Caminada** **Tenaris, Italy**
	Production of tube and pipes, covering heat treatment, linked to metallurgy of this grade and long term properties and non destructive tests. The reason of the recent evolution of ASTM regarding hardness. V&M experience regarding influence of several post welding heat treatment on base material and some metallurgical recommendation concerning PWHT.	**Mr. Bruno Lefebvre** **V&M, France**
SESSION 2	WELDING OF GRADE 91 MATERIALS – PROCESSES, CONSUMABLES	
	Introduction to welding of Grade 91, Requirements on Filler metal, Optimal welding parameters and heat cycle, welding practice, filler metals for USC power plants	**Mr. Amitabha Bhattacharya** **Bohler Welding Group India Pvt. Ltd, Mumbai, India**
	Welding consumables for Grade 91 applications; Special controls in chemistry; PWHT versus creep properties; Difference between - B9 and -9Cb; Tips for successful welding of P91 steel	**Mr. Minoru Otsu** **Kobe Steel, Japan**
	Dissimilar Welding of Grade 91 material with other materials; Critical issues in welding	**Dr. Raghvendra Srivastava** **Metrode Products Limited** **UK**
SESSION 3	FABRICATION AND IN SERVICE BEHAVIOUR OF GRADE 91 MATERIALS …. 1	
	Fabrication welding of 91 grade material – The special care that needs to be taken - Alstom Experience	**Mr. Robert Browning** **Alstom, USA**
	Field welding of tubes and pipes in 91 grade material – Issues; experiences	**Mr. G S Ravishankar** **Tata Consulting Engineers** **Bangalore, India**
	Performance of P91 weldment -- Type IV Cracking, Site Welding Repairs; Dissimilar Weld Issues in service	**Mr. Perrin** **Alstom, USA**

PROGRAMME SCHEDULE

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SESSION 4	**FABRICATION AND IN SERVICE BEHAVIOUR OF GRADE 91 MATERIALS 2**	
	New Generation compact induction heating equipment for local Heat Treatment facilities for Grade 91 material	**Mr. C. N. Kumar** **BHEL, Bangaluru, India**
	NDE of Grade 91 materials and weldment	**Mr. R. J. Pardikar** **BHEL, Tiruchirappalli**
	RLA of Grade 91 Materials(after 15 years in service)	**Mr. P. Nagamanickam** **BHEL, Tiruchirappalli**
SESSION 5	**GRADE 91 MATERIALS – CASTINGS AND FORGINGS**	
	Development of castings in supercritical steels – CFFP Perspective	**Mr. V. K. Agarwal** **BHEL, Haridwar, India**
	Development of fittings and forgings of F91 material – Indian Experience	**Mr. N. D. Makkar** **Flash Forge, Vizag, India**

Introduction to P91/T91 material

Tenaris

Stefano Caminada

Agenda:

- Introduction
- Applications of grade 91
- Chemical composition
- Heat treatment
- Mechanical properties
- Creep properties
- Long term microstructural evolution
- Conclusions

Grade 91 steel:

- Steel for high temperature applications based on 9% Cr and 1% Mo with additions of Nb, V and N
- Developed from 1974 by OAK RIDGE NL (USA)
- Main standards :
  - ASTM A213 (T91)
  - ASTM A335 (P91)
  - EN 10216–2 (2002) X10CrMoVNb 9-1 (Steel number 1.4903)
  - Vd TÜV – Werkstoffblatt 511/2
- First practical use in power plants back in the early 90's in the US and in the UK both for tubes and pipes

Applications of grade 91 steel:

Grade 91 is mainly used:

•Superheaters, headers and steamlines
•Typical working temperatures between 540°C and 610°C

Grade 91 steel use in the USA:

Code	Application	Year Installed	Fuel
RH01	Header	1993	
RH02	Header	1994	
RH03	Header	1999	Oil
RH18	Tube/Pipe	1993	Coal
RH19	Tube/Pipe	1998	Coal
RH20	Tube/Pipe	1998	Coal
RH21	Tube/Pipe	1999	Coal
RH22	Tube/Pipe	1999	Oil
RH23	Tube/Pipe	2000	
RH24	Tube/Pipe	2000	Combined Cycle
RH25	RH and SH outlet pendent tubing /steam Piping/header	2001	Coal
RH26	Tube/Pipe	2001	Combined Cycle
RH27	Tube/Pipe	2001	Combined Cycle
RH27	Tube/Pipe	2001	Combined Cycle
SI	Headers/pipes/ tubing	2000	Combined Cycle
PE1	Superheaters/ reheaters/ seamless main-steam piping/ seamless hot reheat piping/ main-steam and hot reheat safety valves also use P91 forgings for the bodies as do many other high temperature valves. P91 is also used in main-steam and hot-reheat desuperheater liners. Superheater drain system (small bore pipe)		Combined Cycle One conventional coal plant.

Materials and Data Review - A Review of Martensitic 9-12% Chromium Steels for Elevated Temperature Service

ETD Report No: 1089-gsp-113

Grade 91 steel use in the USA :

Code	Application	Year Installed	Fuel	Remarks
M4	Unspecified	1992		
M5	Unspecified	1993		
M6	Thermowells	1993	Coal	
M7	HP Steam Bypass Pipe	2000		
M8	Hot Reheat Steam Bypass Pipe	2000		
M9	Main Steam Pipe	2000		
M10	Main Steam Pipe	2001		New Construction
M11	Division Wall		Oil	Replacement
M12	Division Wall		Oil	Replacement
M13	Division Wall		Oil	Replacement
M14	Unspecified		Oil	

Materials and Data Review - A Review of Martensitic 9-12% Chromium Steels for Elevated Temperature Service

ETD Report No: 1089-gsp-113

Grade 91 steel use in the ROW :

Plant	Country	Size (MW)	Application/ Components*	Year In Which Installed	Temperature °C	Temperature °F	Gauge Pressure MPa	Gauge Pressure ksi
Little Barford CCPP	UK	680	Steam lines	1995-96	540	1004	11.2	1.62
Didcot B CCPP	UK	1370	Steam lines	1996-97	545	1013	12.5	1.81
Connah's Quay CCPP	UK	1400	Steam lines	1996-97	542	1008	11.4	1.65
Ferrybridge	UK	4 x 500	Superheater Headers, Reheat drains	1992 1994	568	1054	16.6 [1]	2.41
West Burton	UK	4 x 500	Superheater Headers	1991	565	1049	16.5 [1]	2.39
Fiddler's Ferry	UK	4 x 500	Superheater Headers	1993	568	1049	16.5 [1]	2.39
Didcot B CCGT	UK	500		1994	565	1049	15.0	2.18
Drakelow C	UK	2 x 325	Headers	1990	566	1051	16.0 [1]	2.32
Tilbury [2]	UK	2 x 350	Superheater Headers	1994	565	1049	15.9 [1]	2.31
Rugeley B	UK	2 x 487	Superheater Headers	1991	566	1051	15.9 [1]	2.31
Ironbridge	UK	2 x 488	Superheater Headers	1990	566	1051	15.9 [1]	2.31
Nefo Nordjylland	Denmark	425	P91-Steam lines, boiler pipes. 10CrMoV?Nb-Turbine rotor	1998	587	1089	31.0	4.5
Skaerbaek	Denmark	425	P91- Steam lines and boiler pipes. 10CrMoV?Nb Turbine	1997	587	1089	31.0	4.5
Schkopau	Germany	2x450	Headers, pipes and fittings	1995	550	1022	28.5	4.13
Schwarze Pumpe	Germany	2x800	Headers, pipes and fittings	1997-98	552	1026	25.7	3.73
Boxberg	Germany	2x800	Headers, pipes and fittings	1997-98	550	1022	28.5	4.13
Lippendorf	Germany	2x930	Headers, pipes and fittings	1999-2000	559	1038	28.5	4.13
La Spezia	Italy	1 unit x 600 MW	Steamlines	2001	568	1054	25.3	3.67
Poolbeg	Ireland	2x150MW	Header + Steam pipe	1997	530	986	8.0	1.16
Ringsend	Ireland	HRSGs	Steam pipe	2001	530	986	8.0	1.16
Moneypoint	Ireland	3x305MW	RHO Header + RH tubing (replacement)	1998-00	~600	1112	4.0	0.58
Kawagoe	Japan			1989	565	1049	30.0	4.35
Black Point	Hong Kong	6X312 HRSGs	Sec. superheater tubes, headers, branch pipes, manifold T-pieces and bi-furcations for P22 main-steam pipes	1993-1998	540	1030	12.8 (set) 10.5 normal	1.85 (set) 1.52 normal
Majuba	South Africa	2 units 600 MW	s/h, r/h headers, interconnecting piping	1994-95	540	1004	18.3	2.65

[1] This is the drum safety valve set pressure = design pressure
[2] Two units decommissioned/mothballed

Materials and Data Review - A Review of Martensitic 9-12% Chromium Steels for Elevated Temperature Service

ETD Report No: 1089-gsp-113

Chemical composition:

Chemical composition according to ASTM A213 and A335:

	C	Mn	Si	P	S	Cr	Mo	V	Nb	Ni	N	Al	Ti	Zr
T91-P91	0.07 0.14	0.30 0.60	0.20 0.50	max 0.020	max 0.010	8.0 9.5	0.85 1.05	0.18 0.25	0.06 0.10	Max 0.04	0.03 0.07	max 0.02	max 0.01	max 0.01

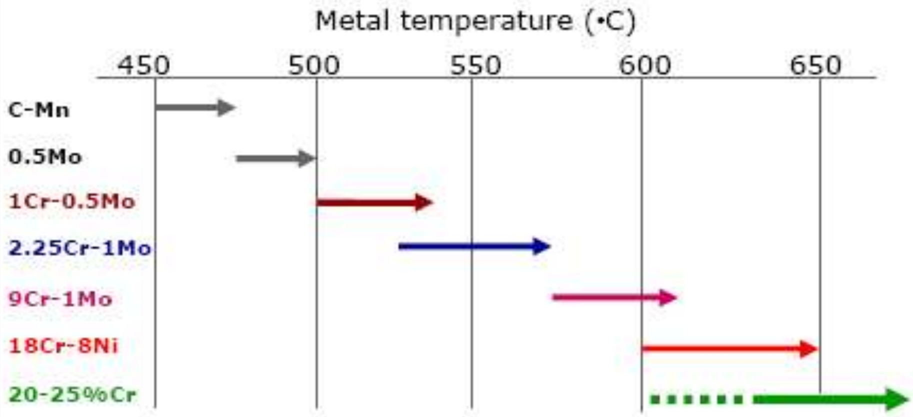
- Cr and Mo to increase oxidation resistance
- Nb, V + N to produce fine precipitates → high creep strength

Grade 91 is a precipitation strengthened alloy:

- Particular care shall be taken to achieve the proper precipitation during fabrication of the tubes/pipes

- Particular care shall be taken during the fabrication of the components not to destroy this essential strengthening mechanism

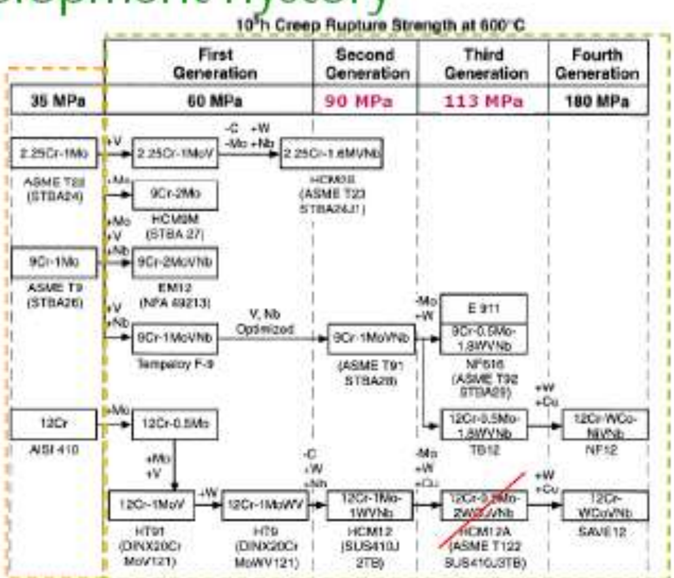
Material selection



Main drivers for the material selection:

- Creep strength
- Steam oxidation/corrosion resistance

Development hystory



F. Masuyama, "New Developments in Steels for Power Generation Boilers",in Advanced Heat Resistant Steels for Power Generation, R. Viswanathan and J.W. Nutting, Ed.; IOM Communications Ltd., London, pp 33-48, 1999.

Chemical composition:

Chemical composition according to ASTM A213 and A335:

	C	Mn	Si	P	S	Cr	Mo	V	Nb	Ni	N	Al	Ti	Zr
T91-P91	0.07 0.14	0.30 0.60	0.20 0.50	max 0.020	max 0.010	8.0 9.5	0.85 1.05	0.18 0.25	0.06 0.10	Max 0.04	0.03 0.07	max 0.02	max 0.01	max 0.01

Function of the main alloying elements:

C: increases the mechanical strength (interstitial atom) and forms carbides and carbonitrides with Cr, Nb, V which improve the creep strength.

It is an austenitizing element (retards the formation of delta ferrite)

Cr: Improves steam oxidation and corrosion resistance; increases the hardenability, forms Carbides (mainly $M_{23}C_6$)

Chemical composition:

Chemical composition according to ASTM A213 and A335:

	C	Mn	Si	P	S	Cr	Mo	V	Nb	Ni	N	Al	Ti	Zr
T91-P91	0.07 0.14	0.30 0.60	0.20 0.50	max 0.020	max 0.010	8.0 9.5	0.85 1.05	0.18 0.25	0.06 0.10	Max 0.04	0.03 0.07	max 0.02	max 0.01	max 0.01

Function of the main alloying elements:

Mo: solid solution strengthening; increases the hardenability, during exposure at temperature forms Laves phase (Fe_2Mo)

N: increases the mechanical strength (interstitial atom) and forms carbonitrides with Nb and V which improve the creep strength. It shall not be bound only to Al: N/Al•3

It is an austenitizing element (retards the formation of delta ferrite)

Chemical composition:

Chemical composition according to ASTM A213 and A335:

	C	Mn	Si	P	S	Cr	Mo	V	Nb	Ni	N	Al	Ti	Zr
T91-P91	0.07 0.14	0.30 0.60	0.20 0.50	max 0.020	max 0.010	8.0 9.5	0.85 1.05	0.18 0.25	0.06 0.10	Max 0.04	0.03 0.07	max 0.02	max 0.01	max 0.01

Function of the main alloying elements:

Nb: carbide and nitride former, very important for creep strengthening as it is necessary to form fine MX

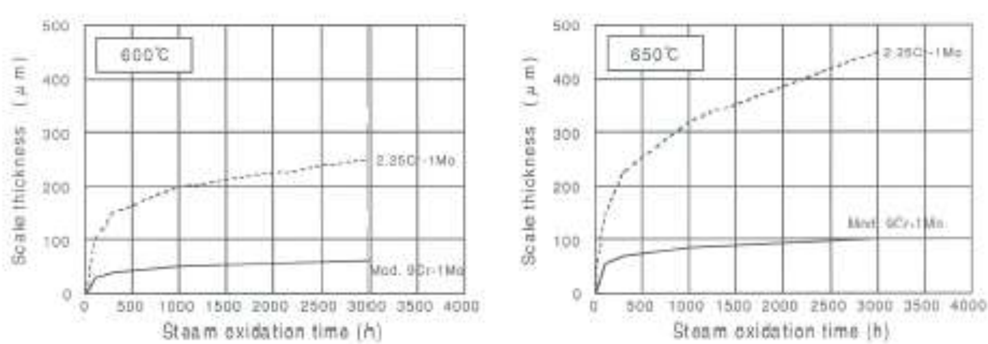
V: carbide and nitride former, very important for creep strengthening as it is necessary to form fine MX

Ni: lowers Ac1 temperature and above 0.6% it is proved to reduce creep resistance. It is recommended to keep Ni•0.3%

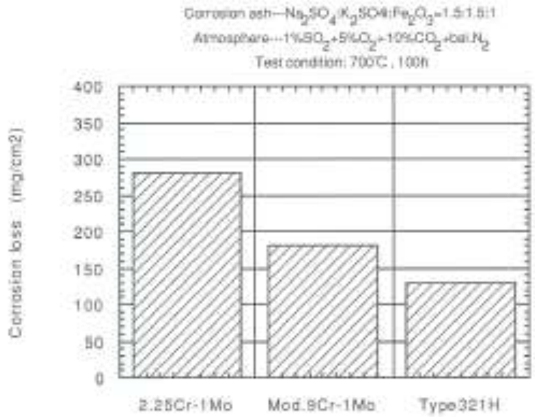
Grade 91 steel: steam oxidation resistance

Steam oxidation temperature : 600 and 650°C

Scale thickness of Mod.9Cr-1Mo steel is thinner than that of 2.25Cr-1Mo steel



Grade 91 steel: hot corrosion resistance



Heat treatment of grade 91:

9%Cr steels are normally **normalized and tempered**:

NORMALIZING: performed at high temperature dissolves into the matrix all the precipitates formed during hot forming and, after cooling, creates a martensitic microstructure

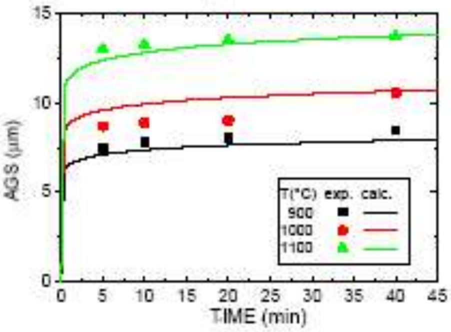
TEMPERING: softening and precipitation of M(C,N) and $M_{23}C_6$

The desired microstructure is **100% tempered martensite**
For thick sections this can be achieved controlling the cooling rate after austenitization (see CCT diagram)

Choice of normalizing temperature:

- High temperatures (>1000°C) are necessary to dissolve the majority of nitrides
- Temperature > 870°C to dissolve $M_{23}C_6$
- Temperature > 900°C to dissolve MX
- Avoid excessive grain coarsening (good mechanical properties)

Fit of the experimental data

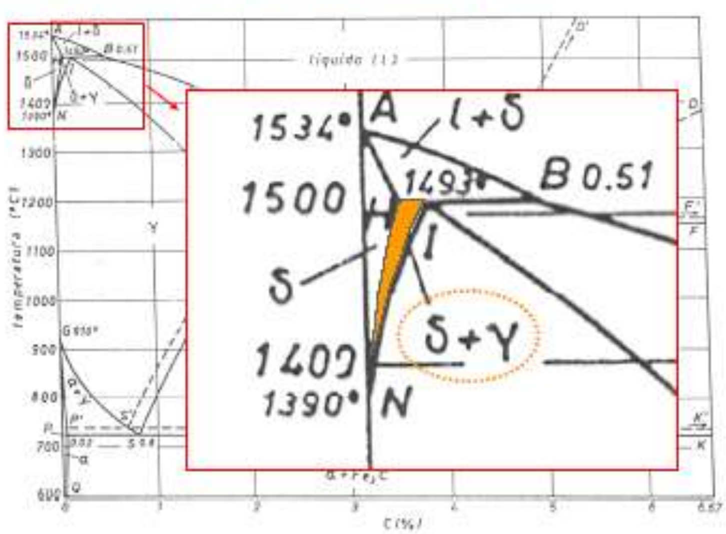


$$d_\gamma(\mu m) = K_1 \exp\left(-\frac{Q}{RT}\right) t^{K_2}$$

d_γ = average Austenite grain size
T = temperature (K)
t = time (s)
R = gas constant (J/K/mol)
Q = activation energy for grain growth (J/mol)
K_1, K_2 = kinetic constants

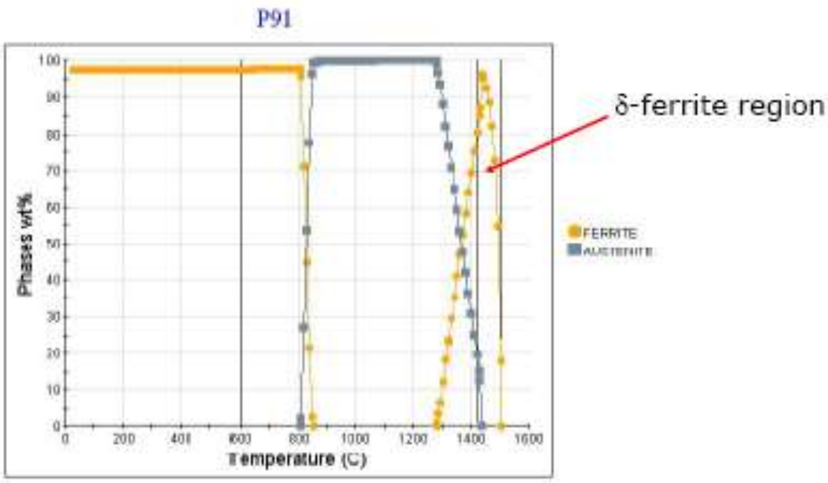
Thanks to NbN, VN and TiC no abnormal grain coarsening below 1100°C

Formation of delta-ferrite:



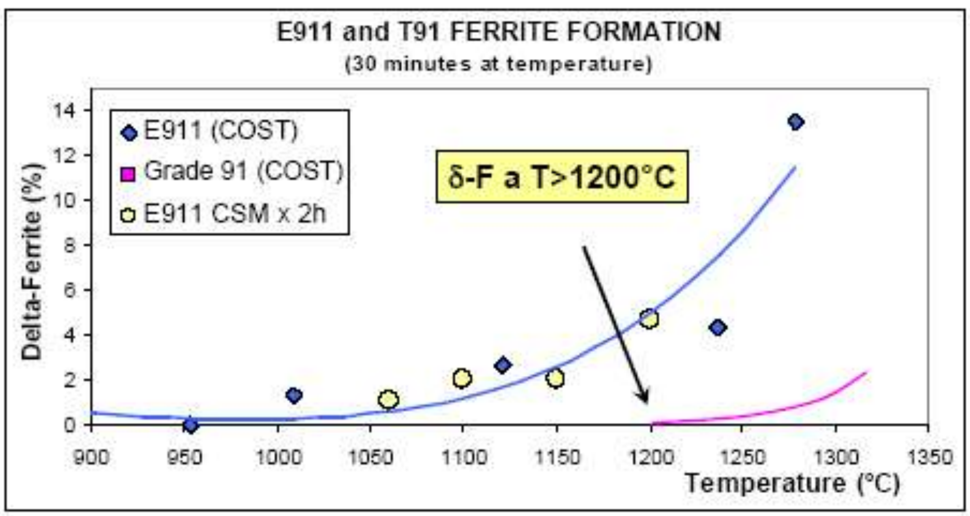
Fe-C equilibrium diagram

Formation of delta-ferrite:



Calculated equilibrium diagram for grade 91 - JMatPro

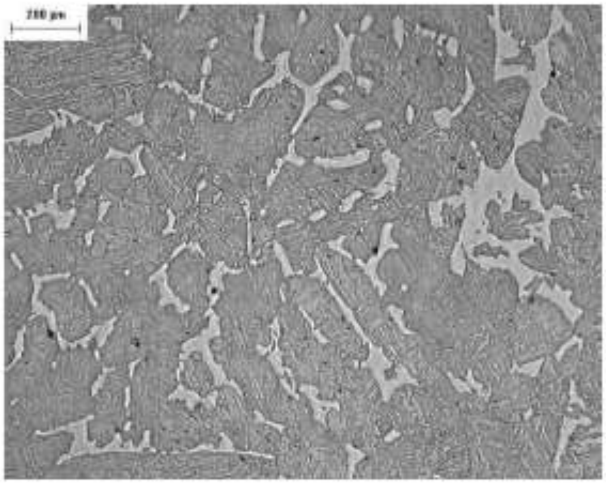
Formation of delta-ferrite:



Long soaking times at high temperature promote **delta-ferrite formation**

Requirement on the microstructure: **delta-ferrite•1%**

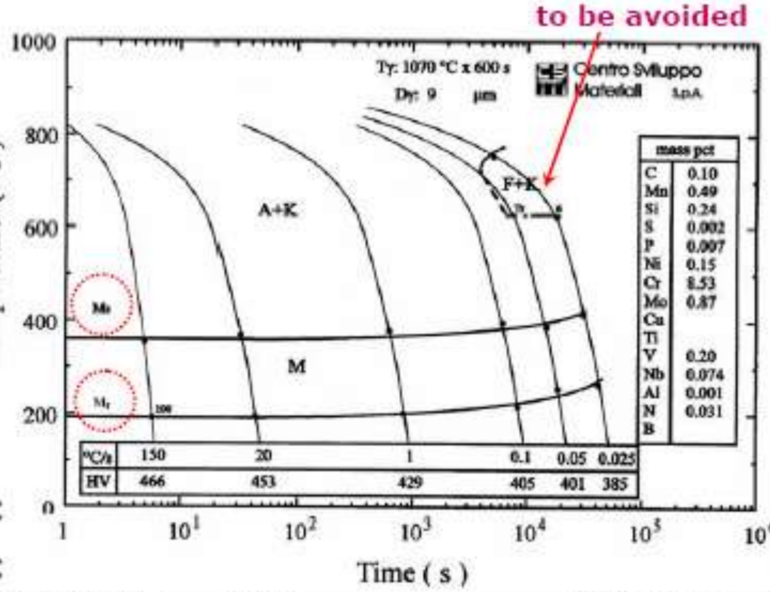
Formation of delta-ferrite:



Example of a non acceptable microstructure: excessive presence of delta-ferrite

CCT curve:

Ferritic nose to be avoided



Ac_1 = 810°C

Ac_3 = 930°C

Normalization at 1060-1080°C:

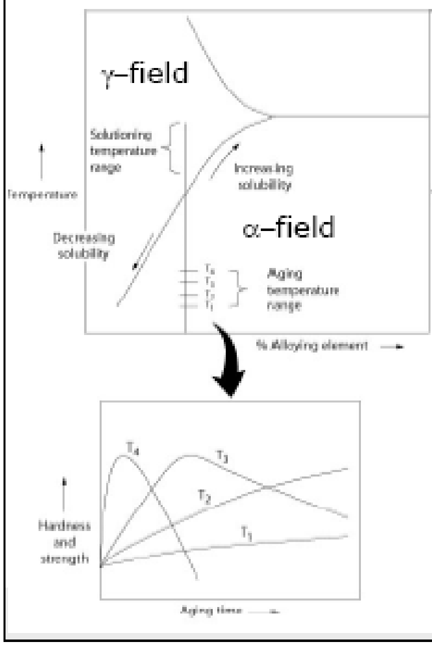
- Good solubilization of precipitates;
- <1% δ-ferrite
- Controlled growth of austenitic grain: $D\gamma < 30\mu m$;
- Martensitic microstructure in a wide range of cooling temperatures: keep cooling rate>0.1°C/s

Tempering 760-780°C:

$$M_3C \rightarrow [\,M_{23}C_6 + M_2X\,] \rightarrow [M_{23}C_6 + MX\,]$$

- Softening (~225 HV);
- Fine and diffuse precipitation of MX (Nb,V)(C,N) into the matrix
- Controlled precipitation of $M_{23}C_6$ along GB and sub-GB, without excessive coarsening
- High tempering temperature allows more room for performing the PWHT

Tempering 760-780°C:



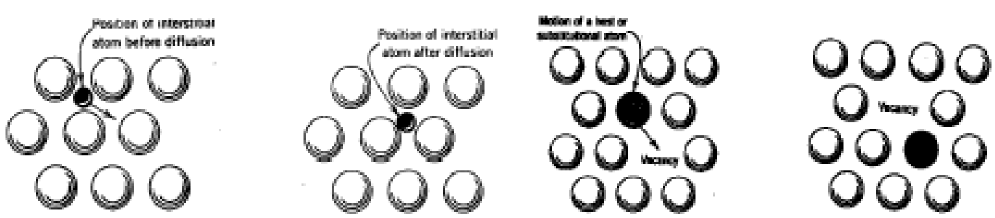
Precipitation hardening involves heating an alloy to a sufficiently high temperature so that enough of an alloying element is dissolved to form a supersaturated solid solution. It is then rapidly cooled to room temperature, freezing the alloying elements in solution. On reheating to an intermediate temperature, the host metal rejects the alloying element in the form of a fine, uniformly distributed precipitate in the alloy matrix.

These fine precipitate particles act as barriers to the motion of dislocations and provide resistance to slip, thereby increasing the strength and hardness.

Source: F.C. Campbell, Ed., Elements of Metallurgy and Engineering Alloys, ASM International, 2008

Diffusion phenomena:

- The formation of precipitates during the tempering heat treatment is a diffusion controlled phenomenon
- The high temperature promotes the movement of atoms inside the lattice
- Diffusion phenomena promote the precipitation of second phases in the supersaturated solid solution obtained with normalizing
- Precipitates are very effective in impeding the movement of dislocations and thus the deformation of the material under load



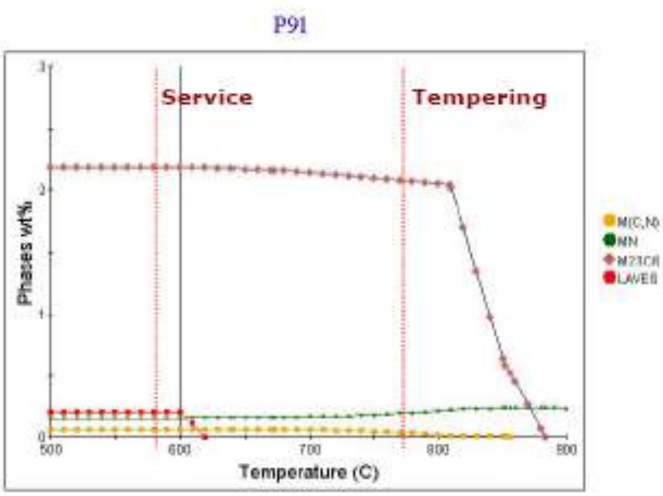
Interstitial atoms

Substitutional atoms

Diffusion phenomena:

- Diffusion is a function of temperature and time
- Diffusion coefficient: **$D = D_o \exp(-Q/RT)$**
  - D_o = constant (m^2/s)
  - Q = activation energy of diffusion (J/mol)
  - R = constant of perfect gases (8.31 J/mol K)
  - T = temperature (K)
- Diameter of the precipitates: **$d = \alpha\,[t^* D_0 \exp(-Q/RT)]^{0.5}$**
  - α is a function of the matrix composition
- Diffusion phenomena can be simply described with a single parameter, called Larson-Miller parameter (LMP) which accounts both time and temperature:
- LMP=(LMC+log(t))(273.15+T)
  - LMC: Larson Miller constant, usually LMC=20
  - t: time
  - T: temperature

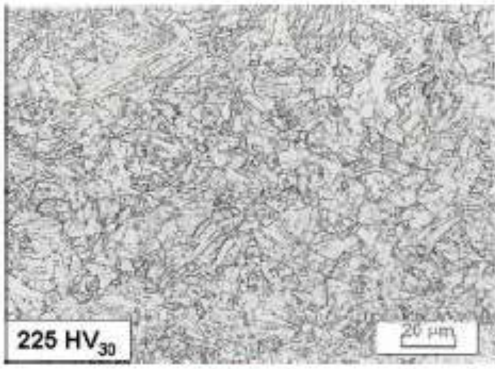
Precipitates in grade 91:

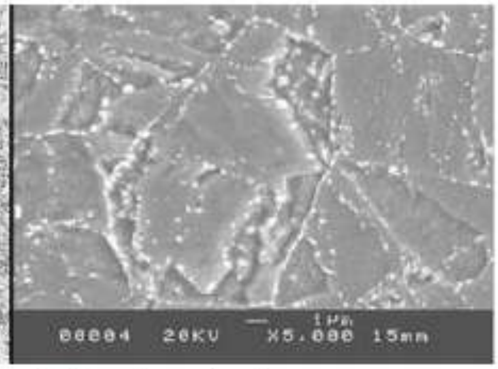


Calculation of precipitates volumes for grade 91 - JMatPro

Microstructure:

Normalizing + Tempering

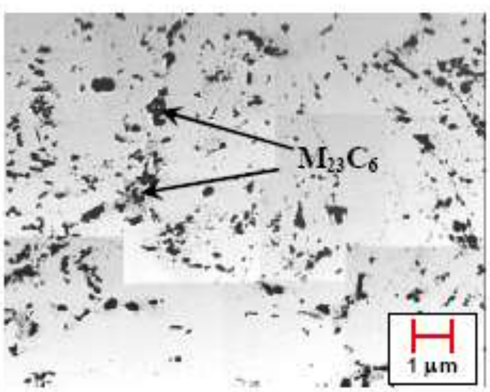


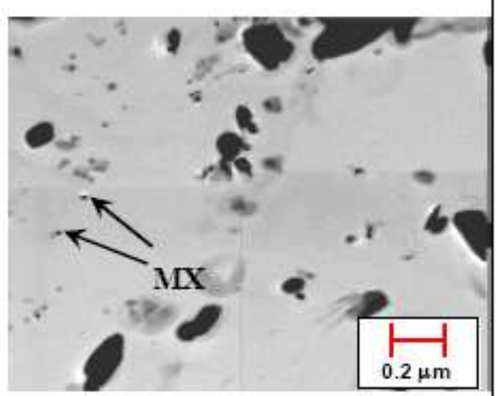


100% tempered martenisitic microstructure

Microstructure (TEM):

Normalizing + Tempering





Mechanical properties:

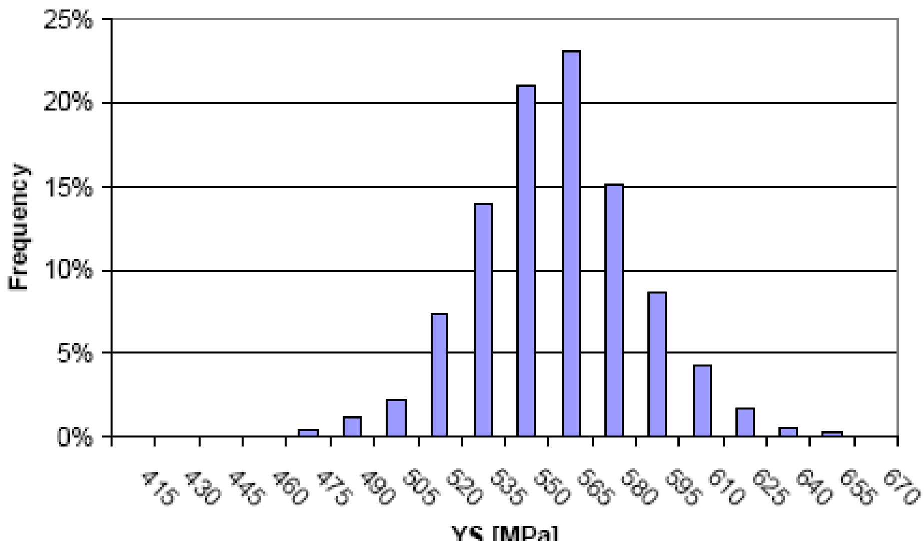
Minimum mechanical properties according to ASTM A213 and A335:

ASTM grade	Hardness (HV_{10})	YS (MPa)	UTS (MPa)
	ASTM	ASTM	ASTM
A213 T91	< 265	> 415	> 585
A335 P91	< 265	> 415	> 585

Important additional requirement:

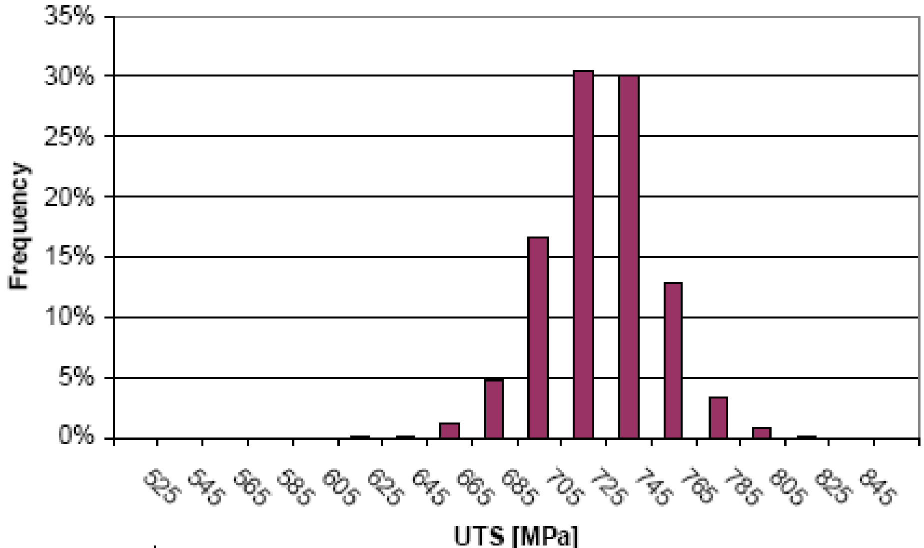
- Hardness: **200• HV10• 265**
- Purpose: to avoid presence of α-ferrite (too slow cooling) or to detect too poor chemistry

T91 Mechanical properties at RT:



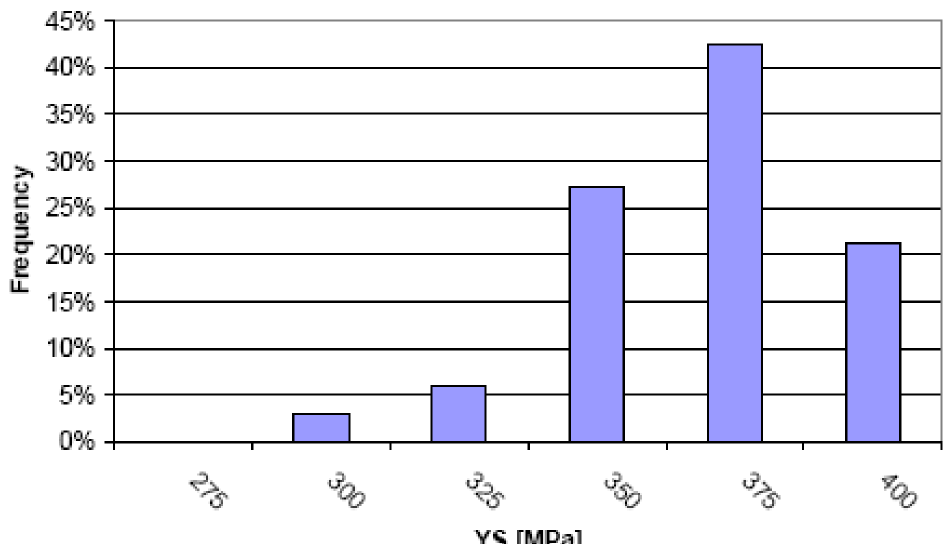
2108 samples

T91 Mechanical properties at RT:



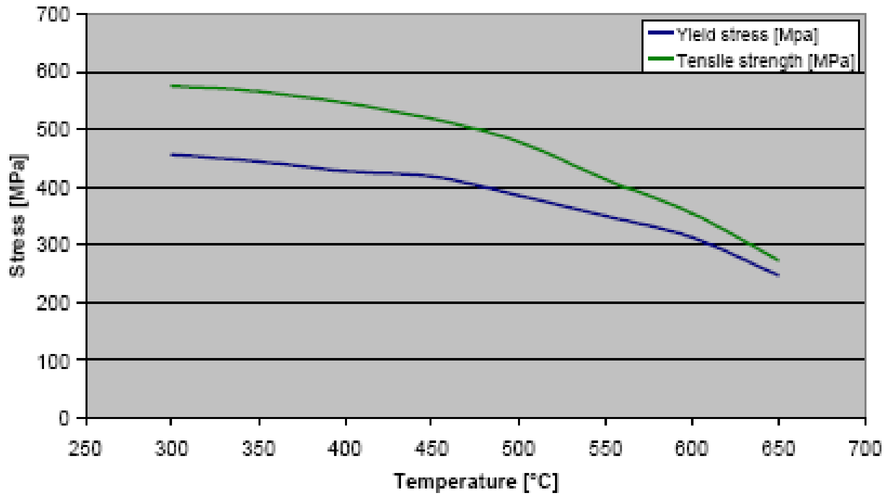
2108 samples

T91 YS at 600°C:

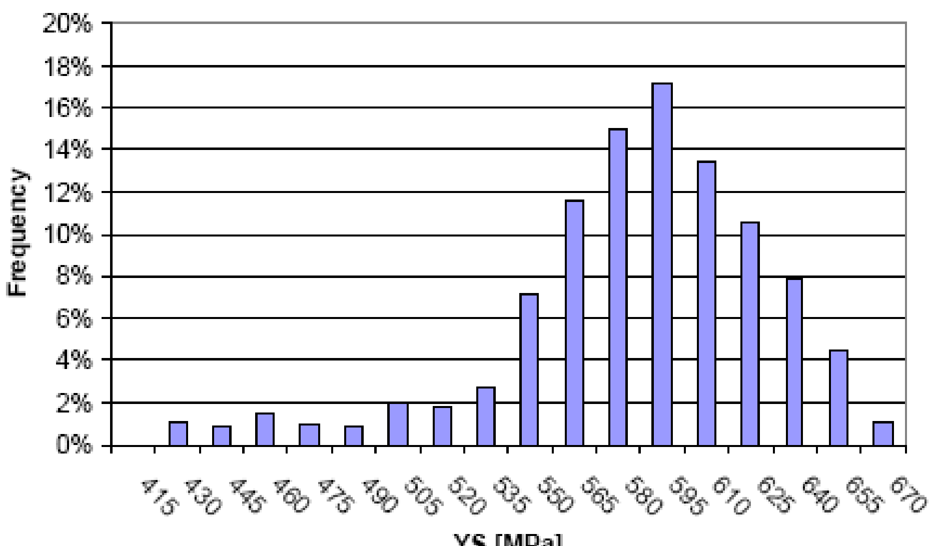


33 samples

Hot tensile properties of T91:

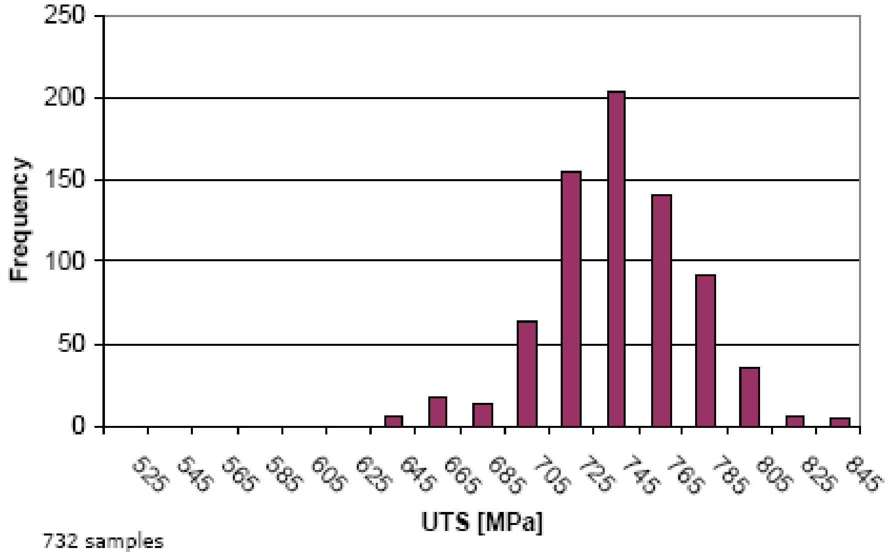


P91 Mechanical properties at RT:



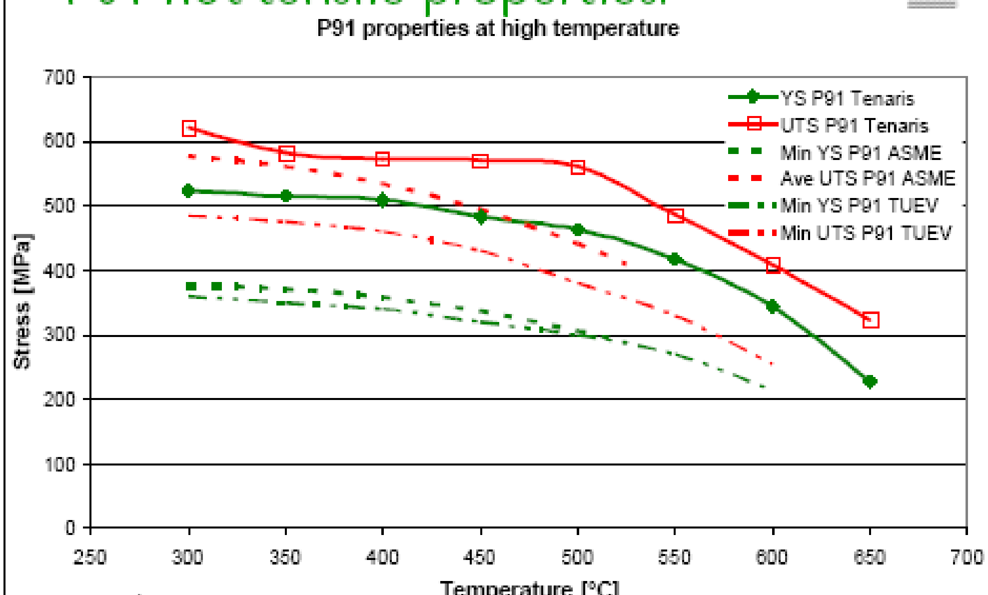
732 samples

P91 Mechanical properties at RT:



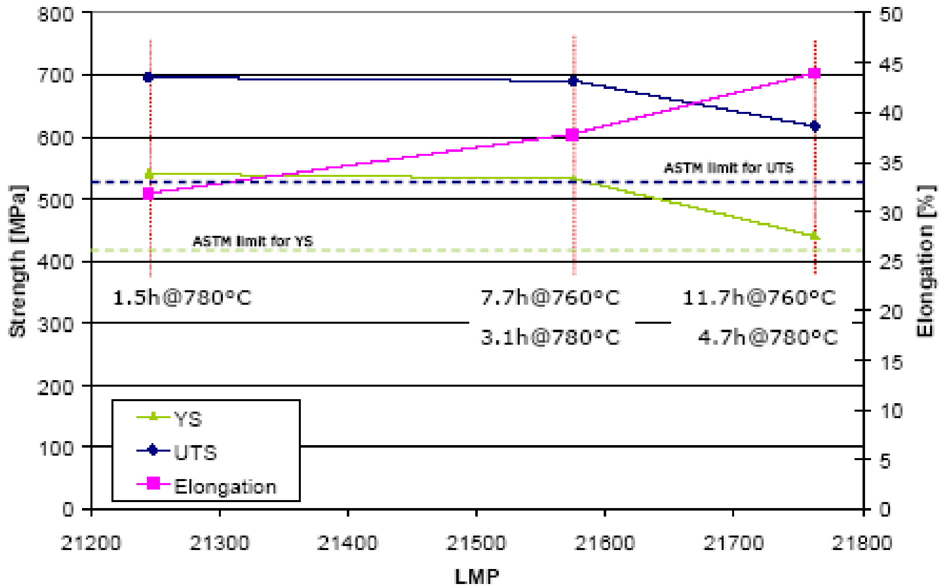
732 samples

P91 hot tensile properties:



44 samples

Effect of tempering on mech. prop.:



Creep properties:

Sensitive information

A creep database with more than 6 milion of creep testing hours is shown. Single test duration exceeding 115,000h (13 years) at 550, 600 and 650°C. On-going tests exceeding 115,000h.

Presented also the 1% creep deformation assessment

For details contact scaminada at tenaris.com

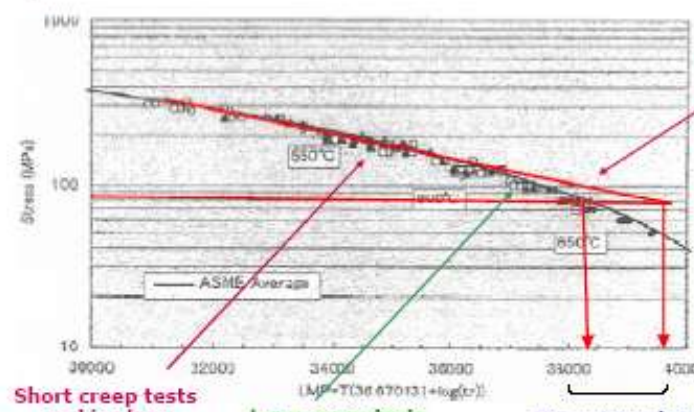
Why a good creep database is so important?

Tenaris has generated long term creep data (single test durations also longer than 115000h, equivalent to more than 13 years) in order to enable reliable extrapolation of the average creep resistance and demonstrate the long term performance of its materials.

If only short term creep data would be available, big extrapolation mistakes could be done, resulting in overestimating the material strength with the risk of unexpected failures in the power plants.

For example some 12%Cr steels, like P122, seemed to have high creep resistance looking only the short term creep tests. But after 10000-30000h of testing it was recognized that these materials had an unstable microstructure that resulted in poor long term creep strength.

Why a good creep database is so important?



Extrapolation from short term data only

Short creep tests and/or low temperature

Long creep tests

Big extrapolation error!!

Creep properties according to ECCC:

Average rupture ☒ creep ☐ relaxation ☐ strengths (% strain)

Temps	10,000h	30,000h	100,000h	200,000h
°C	N/mm²	N/mm²	N/mm²	N/mm²
500	289	273	255	245*
510	270	254	236	225*
520	251	235	217	206*
530	234	218	199	188
540	216	200	182	170
550	200	183	164	153
560	183	167	148	136
570	167	151	132	121
580	152	135	117	106
590	137	120	103	93
600	122	107	90	81
610	109	94	79	71
620	97	83	70	63
630	86	74	62	56*
640	76	65	55	49*
650	68	58	48	43*
660	61	52	42	36*
670	54	46	36	

* Values which have involved extended time extrapolation
( ) Values which have involved extended stress extrapolation

ECCC assessment:

New ECCC assessment of creep rupture strength for steel grade X10CrMoVNb9-1 (Grade 91)

W.Bendick [a], L.Cipolla [b], J.Gabrel [c], J.Hald [d]

[a] Salzgitter Mannesmann Forschung GmbH, D-47259 Duisburg, Germany
[b] Centro Sviluppo Materiali, I-00128 Roma, Italy
[c] Vallourec Research Center CEV, F-59620 Aulnoye-Aymeries, France
[d] Technical University of Denmark, DK-2800 Lyngby, Denmark

International Journal of Pressure Vessels and Piping 87 (2010) 304-309

Other sources of information:

NIMS Material Database (creep data and material properties):

http://mits.nims.go.jp/index_en.html

Tenaris website, Power Generation section:

http://www.tenaris.com/en/Products/PowerGeneration.aspx

Research Institutes with a strong experience on grade 91:

Oak Ridge National Laboratory (USA)

NIMS (Japan) (National Institute for Material Science)

VTT (Finland)

CSM (Italy) (Centro Sviluppo Materiali)

IWS, Graz Technical University (Austria)

Microstructural evolution 1/2

All the advanced ferritic-martensitic grades for Power Generation (like grades 91, 92, 23) and advanced austenitic grades (like TEMPALOY AA-1) achieve their high creep resistance through the precipitation of different type of precipitates in their steel matrix.

In order to be effective for creep strengthening, precipitates must be fine and stable at the service temperature.

However the high service temperatures reached nowadays (metal temperatures higher than 600°C) promote an accelerated diffusion of the elements through the matrix causing changes in the precipitate shape and composition, which could potentially lead to unstable behaviours and unexpected creep failures.

Microstructural evolution 2/2

The chemical composition of the steel and the heat treatment parameters have a strong effect on the stability of the precipitates

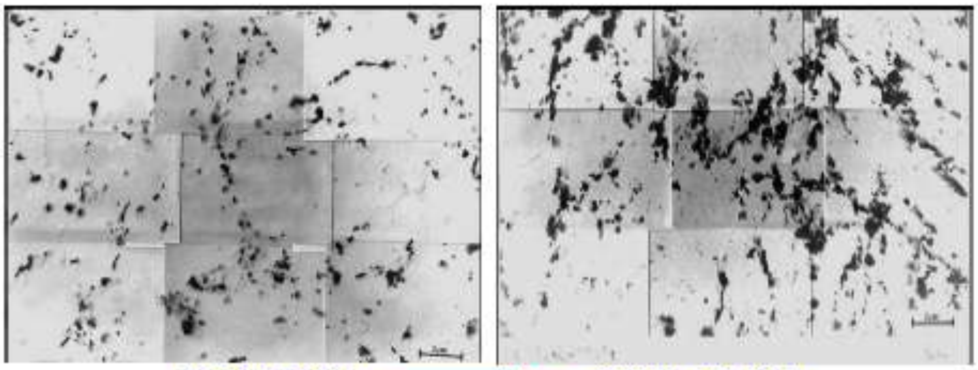
In order to study the evolution of precipitates, samples from long term exposed materials (for example P91 exposed 115,000h at service temperature) have been investigated by means of electronic microscopy (TEM, SEM)

The deep microstructural characterization carried out by Tenaris in these years has enabled to understand the main evolution mechanisms and to guarantee that 9%Cr grades such grade 91 and 92 are very stable over the years.

On the contrary, it has been proved that metastable 12%Cr grades (like grade 122) are unstable because of Z-phase precipitation after few years of service

Microstructural evolution:

Exposure to service temperature (550-650°) determines a progressive evolution of the microstructure, because of precipitate coarsening, coalescence and of nucleation and growth of new phases



AS-TREATED → **650°C 58,439 h**

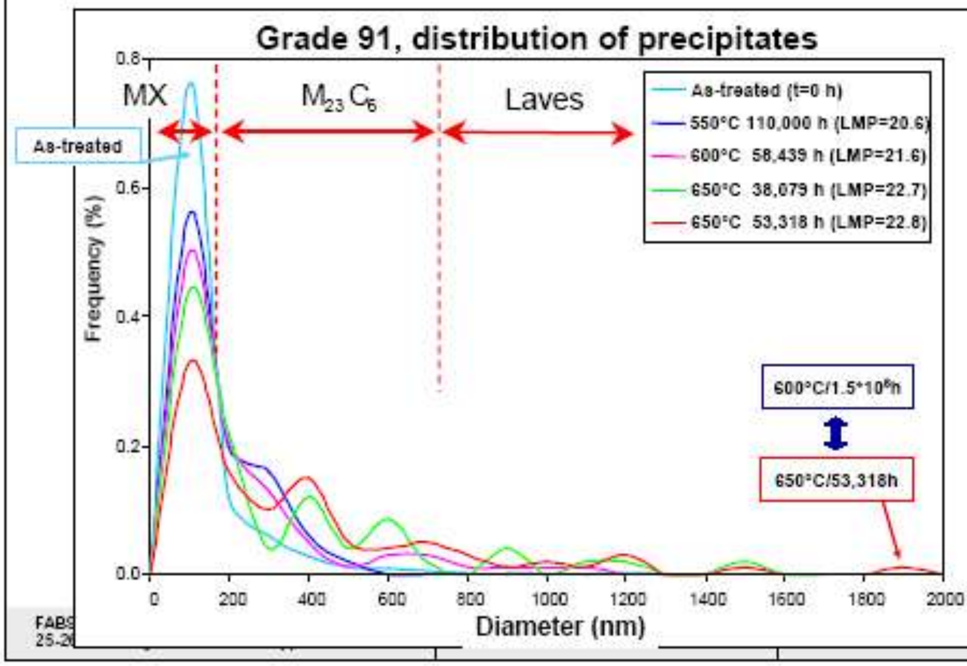
Fine precipitates along GB | **Coarsening of precipitates**

Microstrural evolution:

Main causes of microstructural evolution of grade 91 due to the prolonged exposure to service temperature:

- Coarsening of carbides, in particular of $M_{23}C_6$
- Precipitation of the Laves (Fe_2Mo) phase
- Transformation of MX carbides into Z phase (CrNbN) – very slow kinetic in 9%Cr steels (>>100kh)

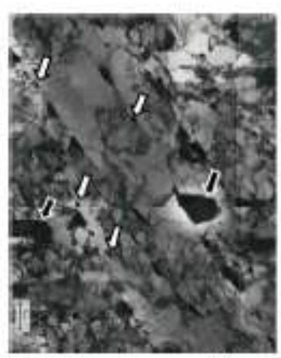
Microstructural evolution:



Microstructural evolution:

As-treated

550°C – 115kh

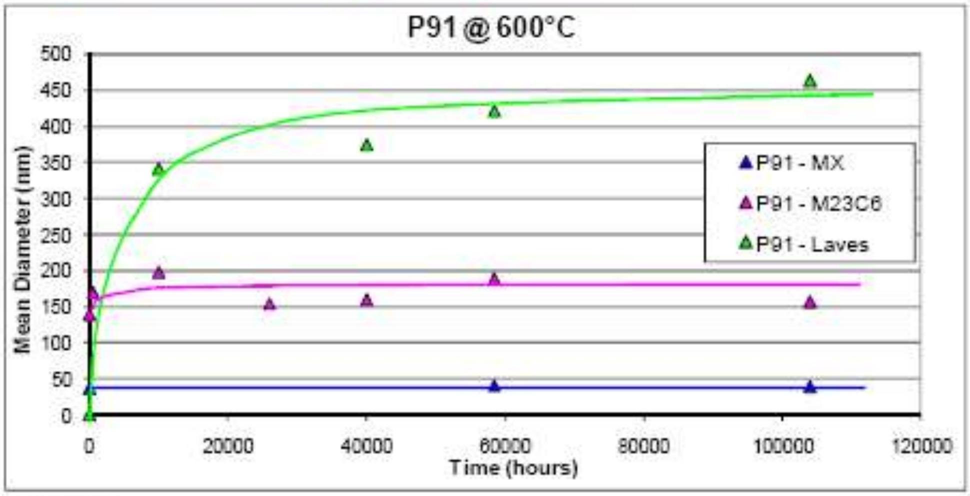


600°C – 104kh

After long exposure at 550°C and 600°C, the substructure does not exhibit significant changes: the tempered martensite lath can be still recognized in many regions.

Precipitates are also indicated: black arrows: Laves phase; white arrows: $M_{23}C_6$

Evolution of precipitates:



@ 600°C

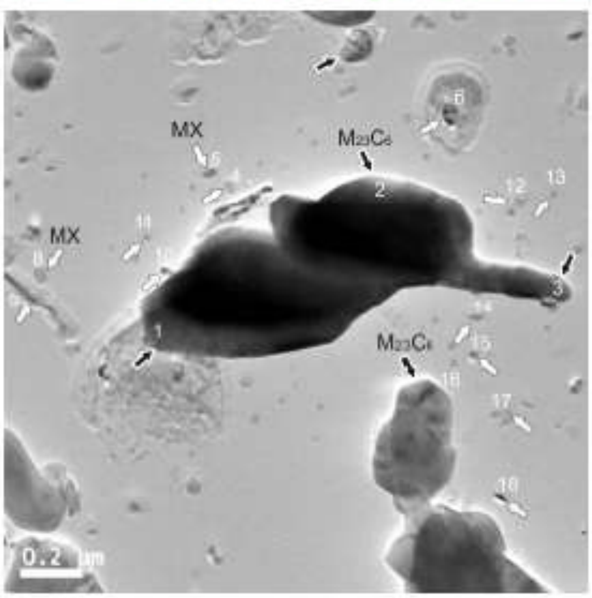
MX diameter < 50 nm

$M_{23}C_6$ diameter < 200 nm

Laves diameter < 450 nm

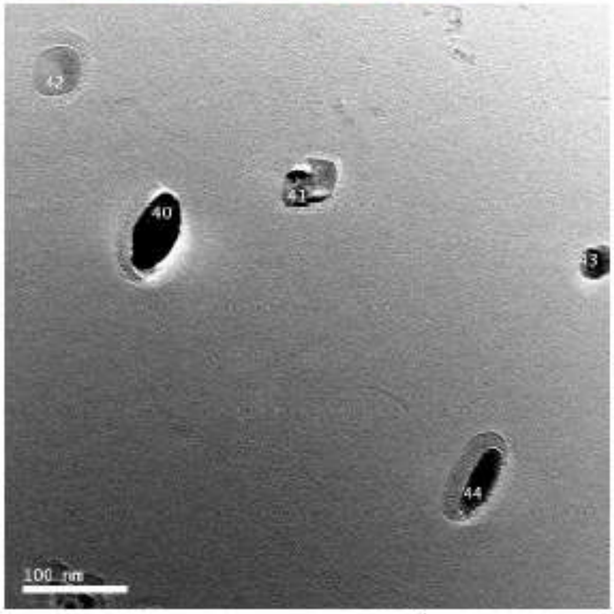
100 EDS each sample

Evolution of $M_{23}C_6$ and MX:



P91, after 104kh at 600°C

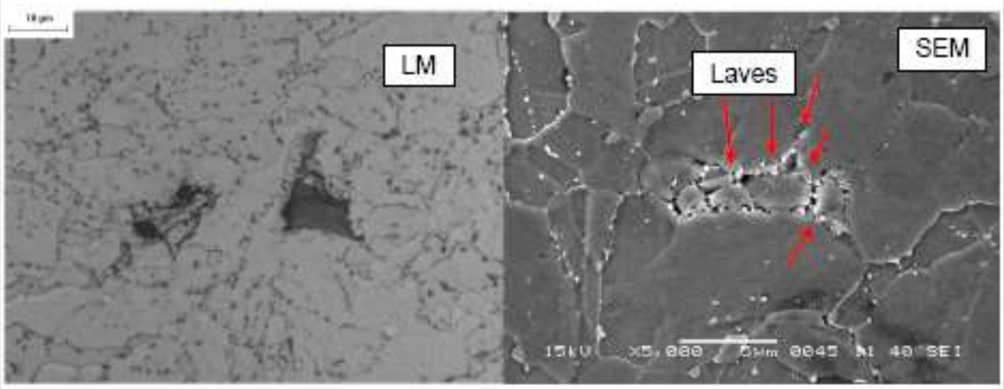
Evolution of MX:



Spectrum	V	Cr	Fe	Nb	Mo	Type
	wt	wt	wt	wt	wt	
Sp40	67	10	0	20	3	MX
Sp41	68	14	1	12	5	MX
Sp42	61	13	1	23	2	MX
Sp43	38	10	1	48	2	MX
Sp44	61	12	0	25	1	MX

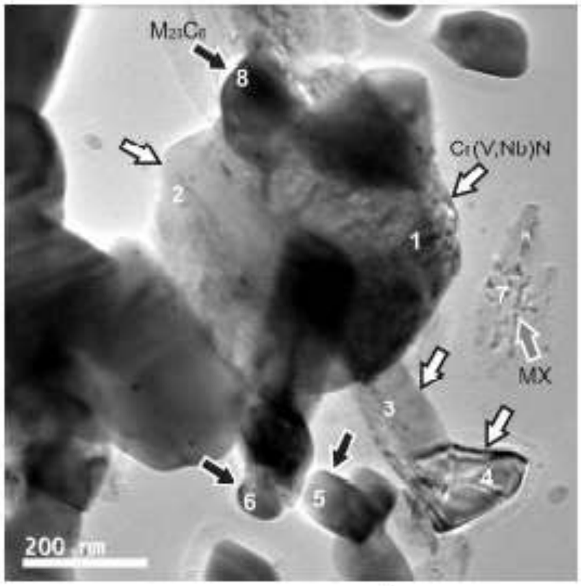
115kh @ 650°C

Laves phase:



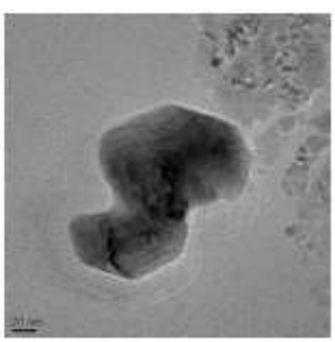
P91 after 20,014 h at 650°C

An example of Z phase particle:

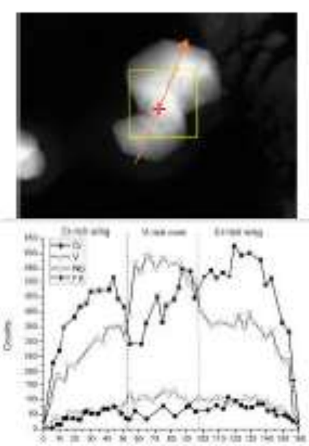


P91, after 104kh at 600°C

Origin of Z phase:



a) Bright field image.



b) EDS linescan.

P91, after 104kh at 600°C

Wrap-up:

The following topics have been covered:

- Introduction
- Applications of grade 91
- Chemical composition
- Heat treatment
- Mechanical properties
- Creep properties
- Long term microstructural evolution
- Conclusions

Conclusions:

- Grade 91: an advanced 9%Cr steel for high temperature application
- Tempered martensite microstructure after N+T
- Creep strengthening due to precipitation of MX and $M_{23}C_6$
- High steam oxidation and hot corrosion resistance
- High creep resistance
- Outstanding long term microstructural stability, proven with long term creep and microstructural evolution data
- The presence of Z phase after 100kh at 600°C is negligible. Z-phase formation cannot be accounted as a degradation mechanism for 9% Cr steels
- Manufacturing and fabrication cycles must preserve the fine precipitates which strengthen this material

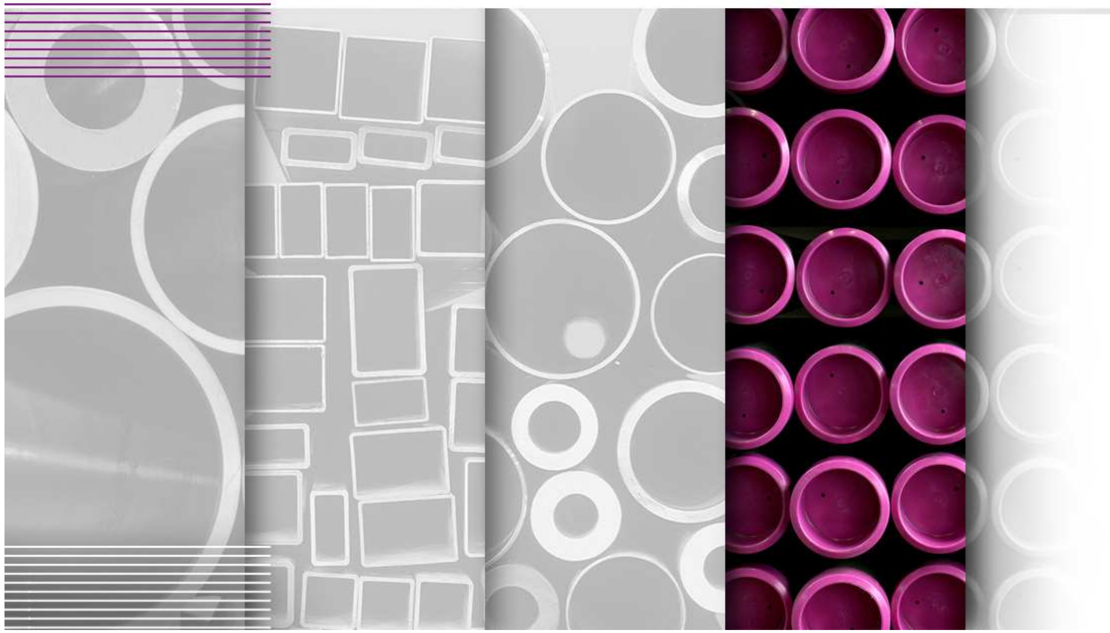
Conclusions:

- Grade 91 is an advanced material requiring clear and robust specifications
- Its metallurgy is much more complex than those of conventional carbon and low alloy grades (ASTM A106 gr. C, ASTM A335 P22)
- Long term properties depend on the optimization of chemistry, processing and heat treatment
- Choosing experienced suppliers means having best quality material, long term performance and free full technical support
- Fabrication of the components shall take into account the complexity of grade 91 microstructure

BACK

VALLOUREC & MANNESMANN TUBES

V&M Experience in T/P91 Tubes and Pipes



Powergen Division

Bruno Lefebvre

Technical Customer Service

Summary

- Introduction on T/P 91
- Tubes and Pipes Production
  - Pre-material
  - Hot rolling
  - Heat treatment
  - Mechanical properties on V&M products
  - NDT
- Focus on hardness
- Focus on welding and PWHT

History of T/P 91

- 1950 Low alloy CrMo steels
- 1960 First super 9%Cr steel (EM12 = 9%Cr- 2%Mo- Nb-V) in France
- 1970 Development of 12%Cr, X20 in Germany
- 1982 Knoxville conference : Presentation of a 9Cr-1Mo steel datapackage
- 1983-84 ASTM approves modified 9Cr-1Mo in A213 (T91)and A335 (P91). Introduction of T91/P91 in ASME code.
- 1989: First V&M deliveries of T91 and P91
- 2000-2010: Large worldwide experience of the grade for sub-critical, super-critical and combined cycle boilers:

More than 300 000 tons of T/P91 delivered by V&M in the last 10 years

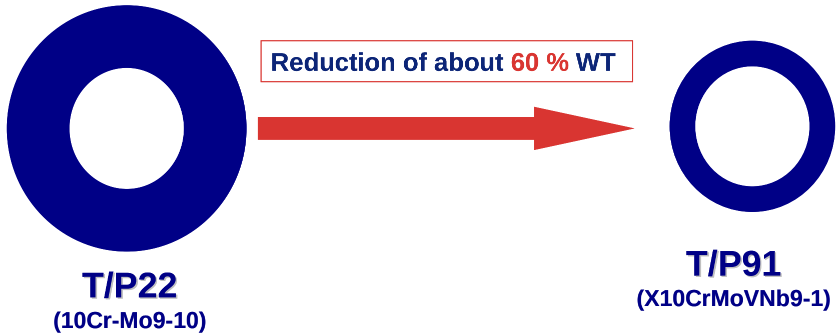
Main advantages of T/P 91

- Good mechanical characteristic and creep resistance up to 600℃
- Significant reduction of WT compared to T/P22
- Allow use at higher temperature
- Good thermal conductivity
- Low thermal expansion

Steam severe conditions

550 ℃ - (1,020 ℉)

250 bars - (3,600 psi)



T/P 91 is widely used in all sub-critical or super-critical power plant for:

- Super heater and reheater tubes
- Headers
- Main Steam piping and hot reheat piping

T/P91 Chemical composition

Grades		C	Mn	P	S	Si	Cr	Mo	V	W	Nb (Cb)	B	N	Ni	Al
T/P22	min	0,05	0,30	-	-	-	1,90	0,87							
	max	0,15	0,60	0,25	0,25	0,50	2,60	1,13							
T/P9	min	-	0.30	-	-	0.25	8.00	0.90							
	max	0.15	0.60	0.025	0.025	1,00	10,00	1.10							
T/P91	**min**	**0.08***	**0.30**	**-**	**-**	**0.20**	**8.00**	**0.85**	**0.18**	**n.s.**	**0.06**	**n.s.**	**0.030**	**-**	**-**
	max	**0.12***	**0.60**	**0.020**	**0.010**	**0.50**	**9.50**	**1.05**	**0.25**		**0.10**		**0.070**	**0.40**	**0.02**
T/P92	min	0.07	0.30	-	-	-	8.50	0.30	0.15	1.5	0.04	0.001	0.03	-	-
	max	0.13	0.60	0.020	0.010	0.50	9.50	0.60	0.25	2.00	0.09	0.006	0.07	0.40	0.02

(Ti and Zr contents: 0.01max according to ASTM Standards)

* C 0,07 / 0,14 for A/SA 213

Tubes and Pipes Production

Integration of our production process

Scraps, Iron Ore, Coke, Charcoal

↓ ***Steel Making***

Steel bar or ingot

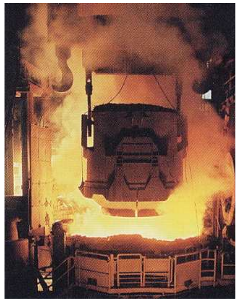
Hot Rolling

↓ ***Tubes and Pipes Manufacturing***

Hot Finished Tubes and Pipes

V & M Steel and Tubes Works

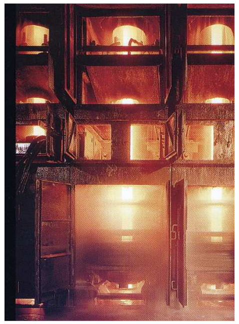
Steel plant process for production of T/P91 bars



1 - Furnace loading

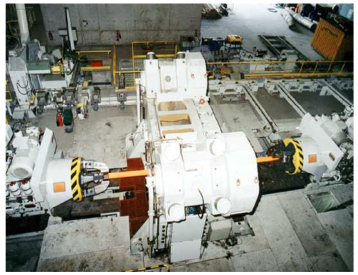
2 - Melting in the ultra-high power electric furnace

3 - VOD plant



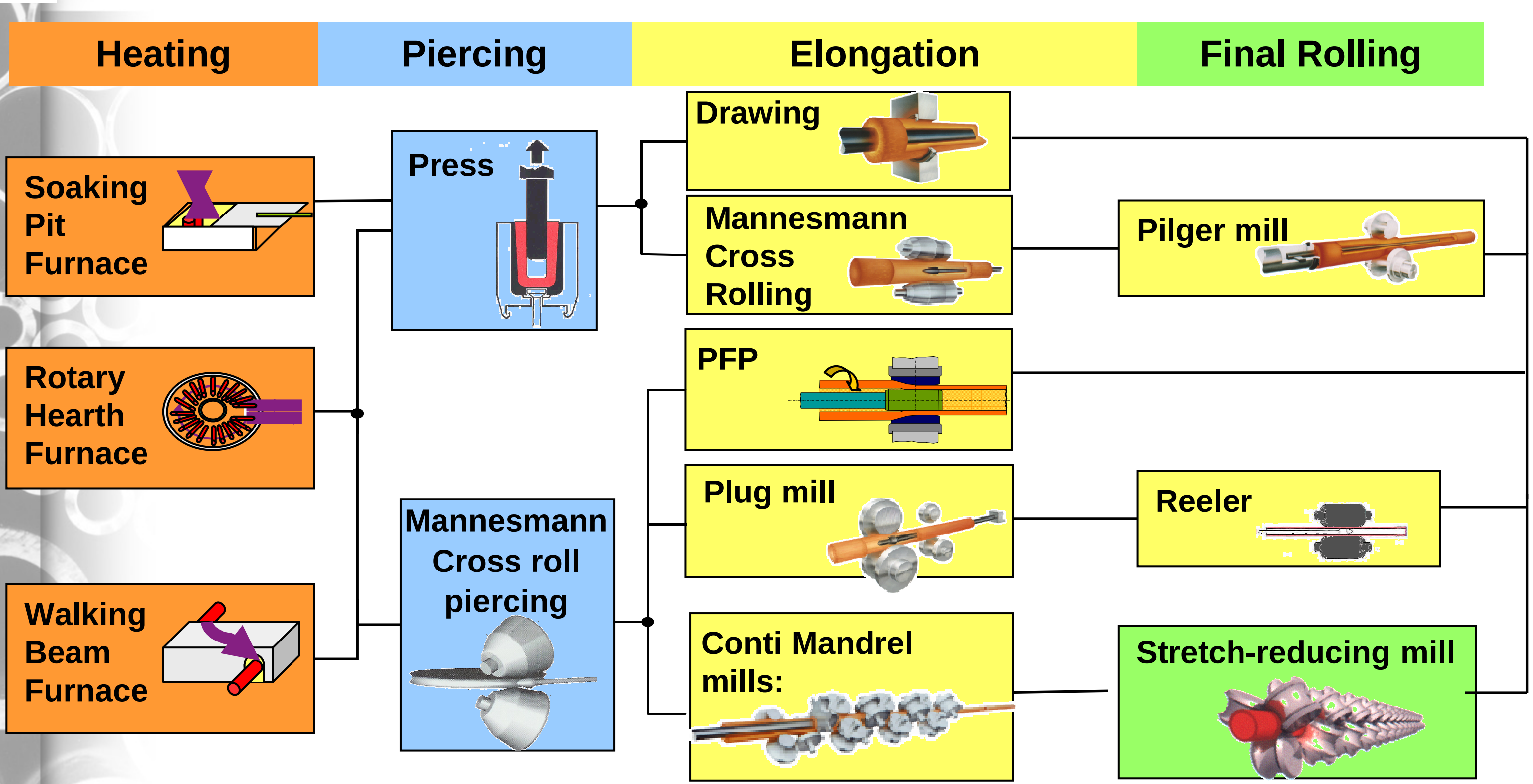
4 - A bowtype continuous casting plant has replaced the old vertical rotary caster

5 - Cooling bed



6 - Hammer forging machine

Hot Rolling Process inside V&M



Continuous Mandrel Mills

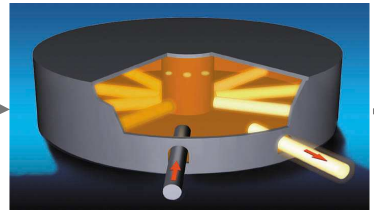
- St-Saulve
- Mülheim

Outside diameters: 26.9 to 180 mm (1.1“ to 7.1“)

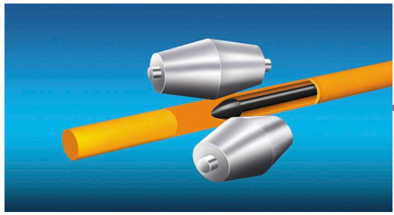
Main Process at Continuous Rolling Mill

Billet Storage

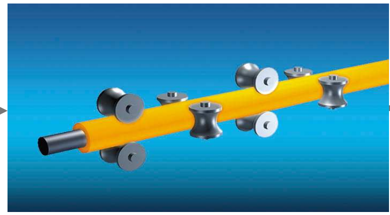
Billet saw



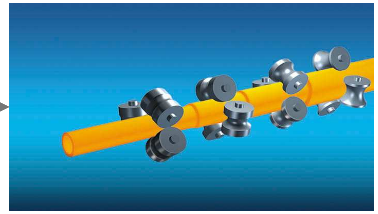
Furnace



Piercing Mill



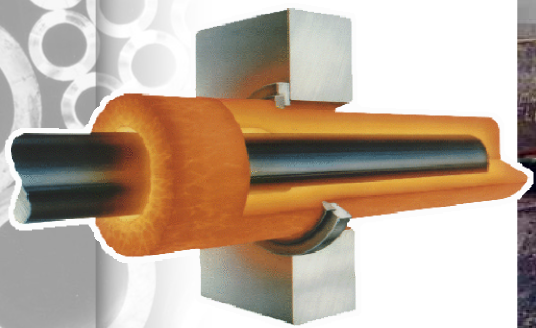
Continuous mandrel Mill



Stretch reducing Mill

Pierce and Draw Process

Reisholz



Outside diameters: approx. 300 to 1,500 mm

WT : 20 to 150mm

Production Steps in Reisholz
for Pipes up to 1500mm OD and 150mm WT

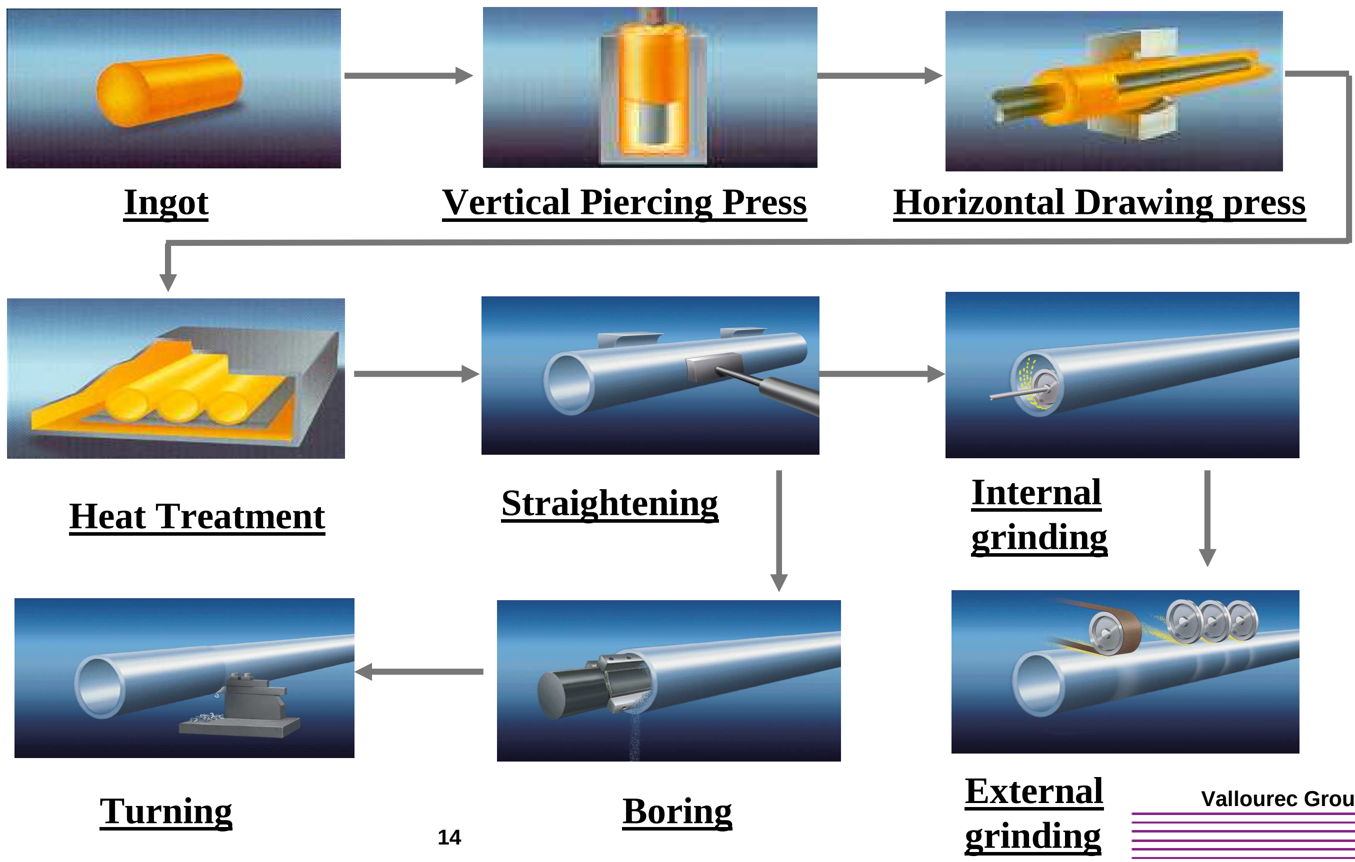
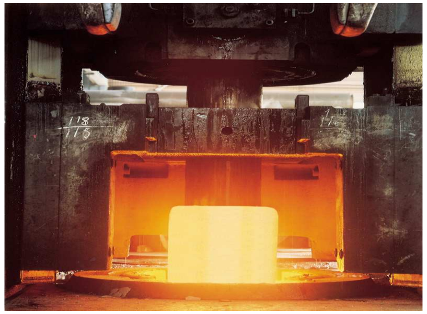


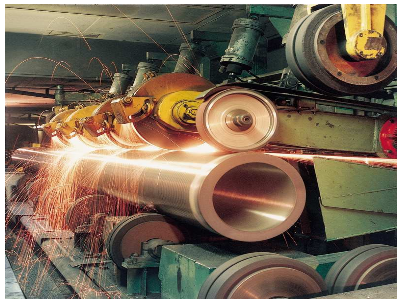
Photo of the Main Production Steps in Reisholz



Vertical Piercing Press

Horizontal Drawing Press

Heat Treatment



External grinding

Turning

Example of P91 products

Dimensional range :

OD from 31.8 to 1500mm

WT from 3 to 150mm

Heat Treatment:
a key point for the properties of T/P91

Heat treatment: a key point for quality of T/P91

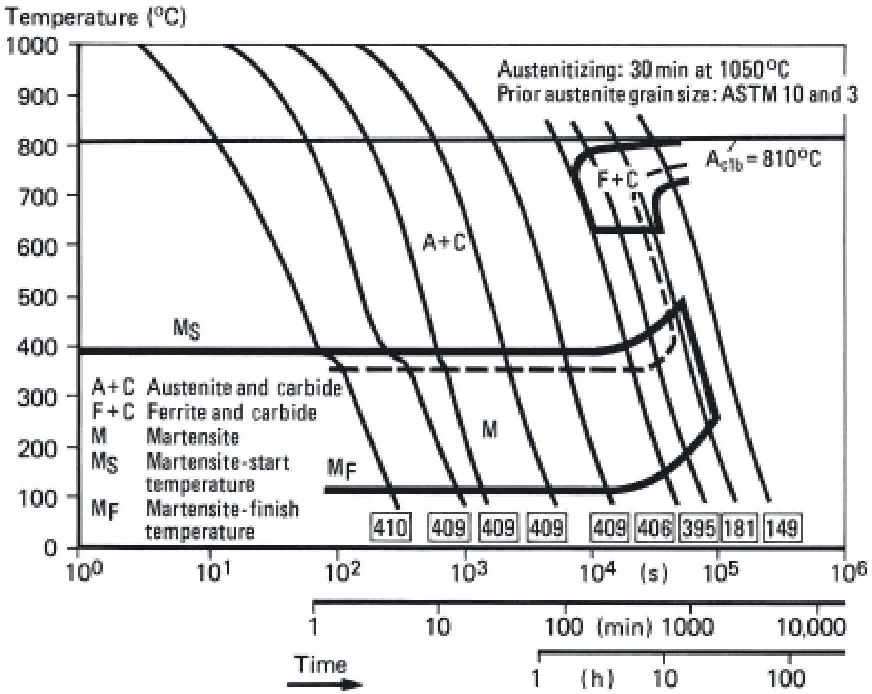
V&M

- Depending on the product size, heat treatment is performed in:
- Batch furnace
- Walking beam furnace
- Tunnel furnace

Batch furnace at Rath

CCT Diagram of T/P91

Chemical composition (%)	C	Si	Mn	P	S	N	Al	Cr	Ni	Mo	V	Nb
	0.11	0.32	0.47	0.014	0.0030	0.038	0.018	8.50	0.13	0.85	0.22	0.076



- AC1 : between 800 and 830℃, but depend on chemistry (Ni + Mn)

➡ temperature of tempering or PWHT

- Ms= martensite start , around 400℃

➡ interpass temperature

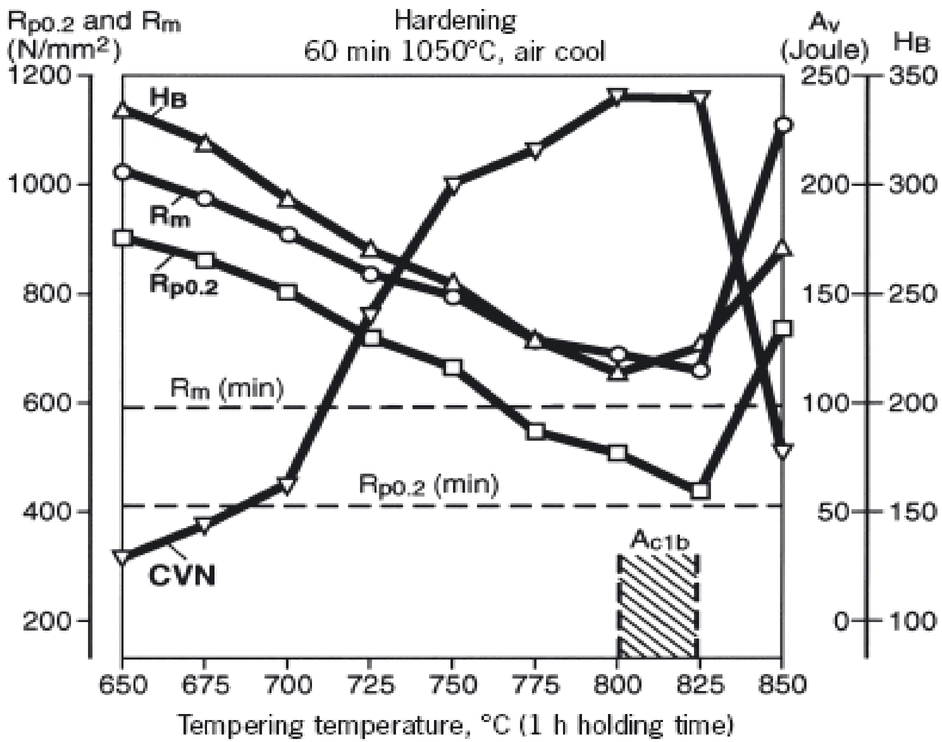
- Mf = martensite finish , above 100℃

➡ cooling prior tempering or PWHT

- Martensite structure with hardness above 400HV even after air cooling of thick pipes.

➡ risk of cracks

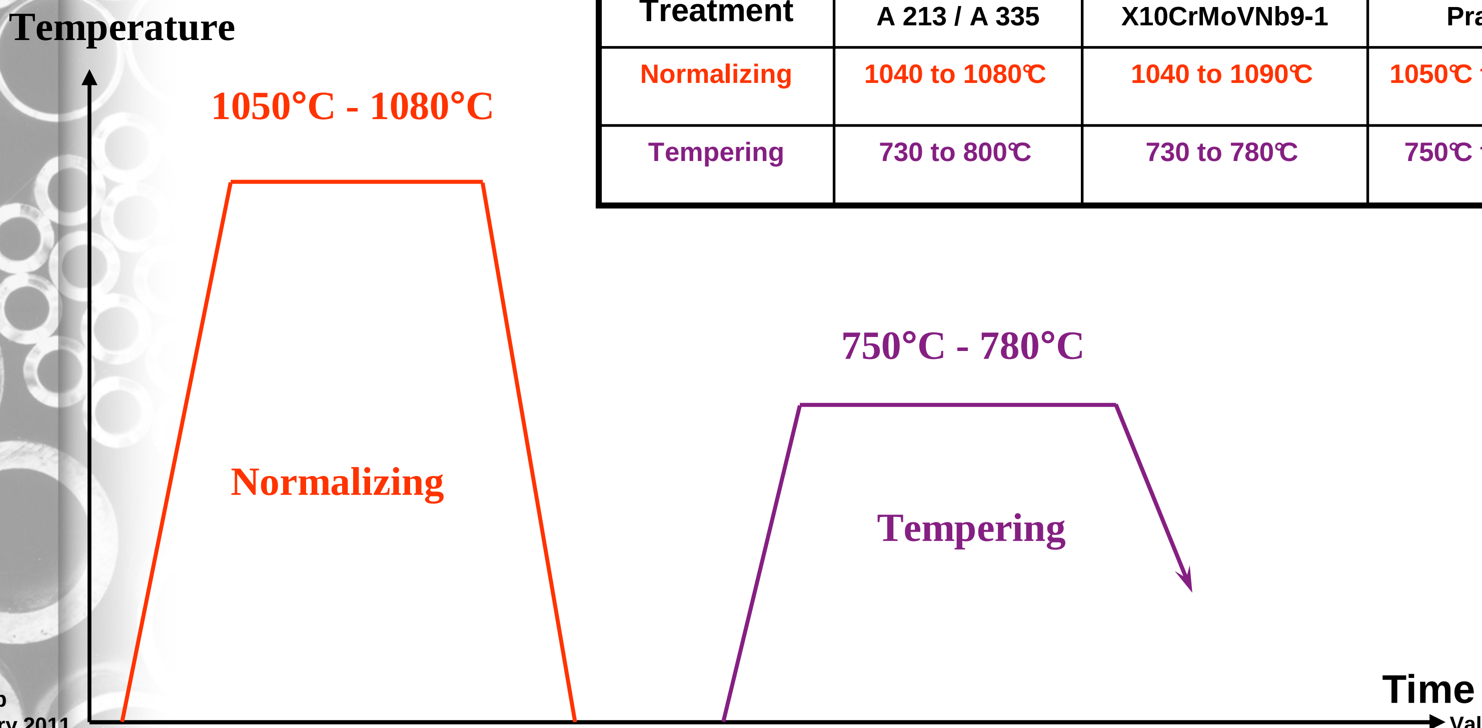
Tempering curve of T/P91



- Tempering at 750℃ / 780℃ optimum range for tensil e and impact properties

T/P91 Industrial Heat Treatment

Heat Treatment	ASTM A 213 / A 335	EN10216-2 X10CrMoVNb9-1	V&M Practice
Normalizing	1040 to 1080℃	1040 to 1090℃	1050℃ to 1080℃
Tempering	730 to 800℃	730 to 780℃	750℃ to 780℃



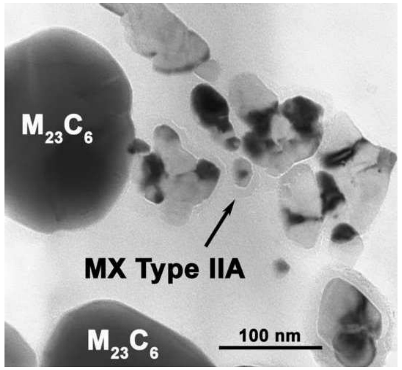
Microstructure of T/P91

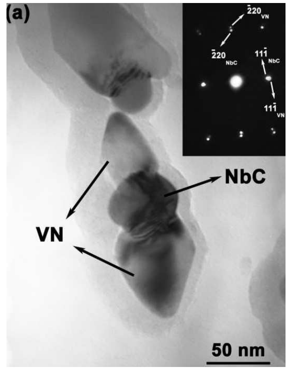
Light optical microscopy

500:1 (etchantV2A)

Tempered martensite microstructure

Transmission electron microscopy



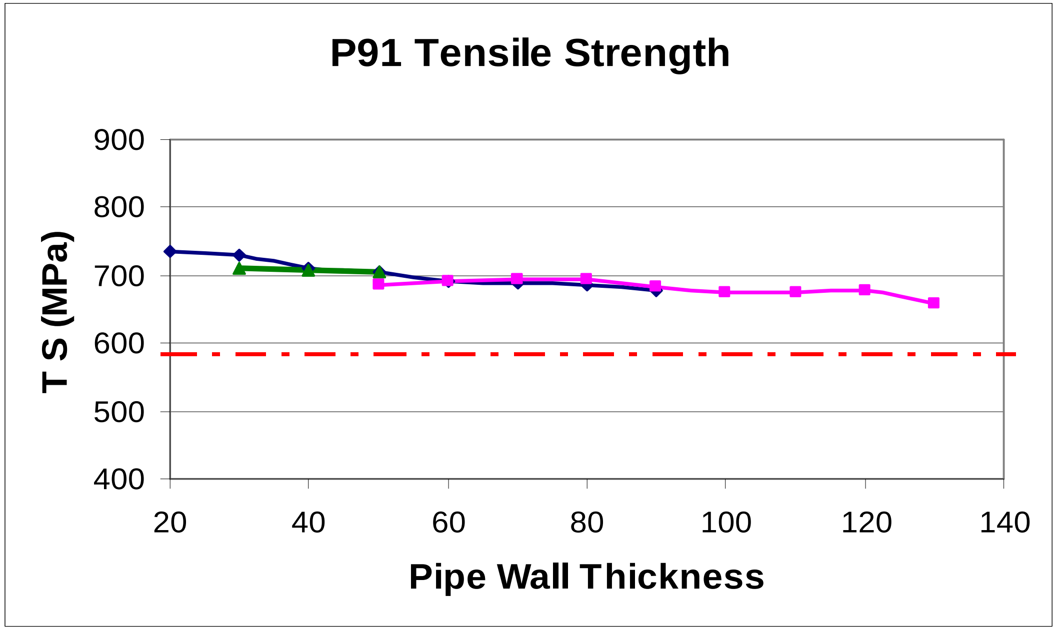


Fine microstructure composed of tempered martensite:

- **M23 C6** *M = Fe , Cr or Mo*
- **MX** *M = V or Nb* *X = N or C*

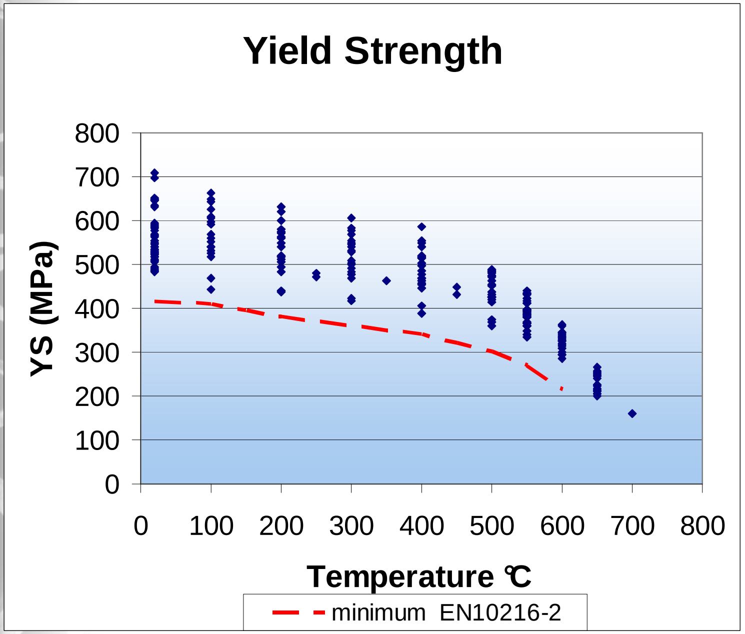
Influence of the Pipe Wall Thickness on Tensile Strength

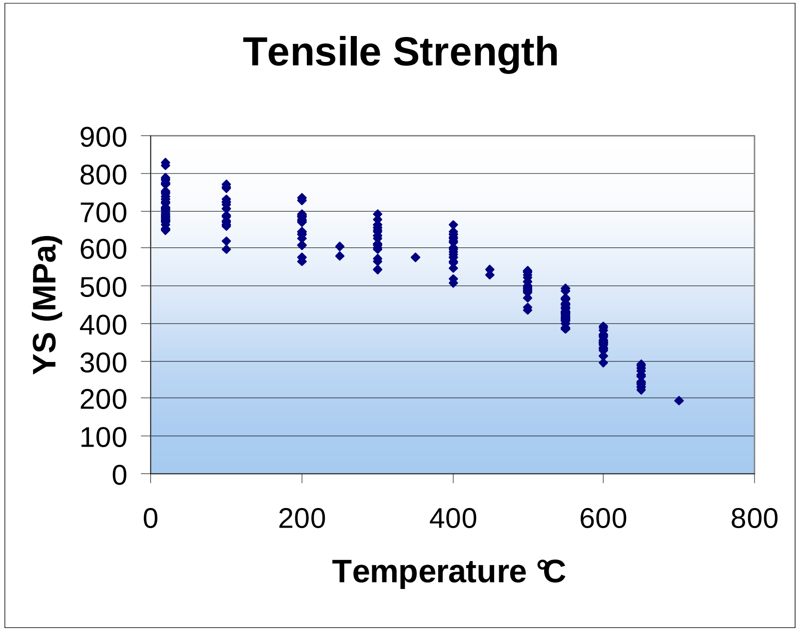
Average data from different furnaces and different mills



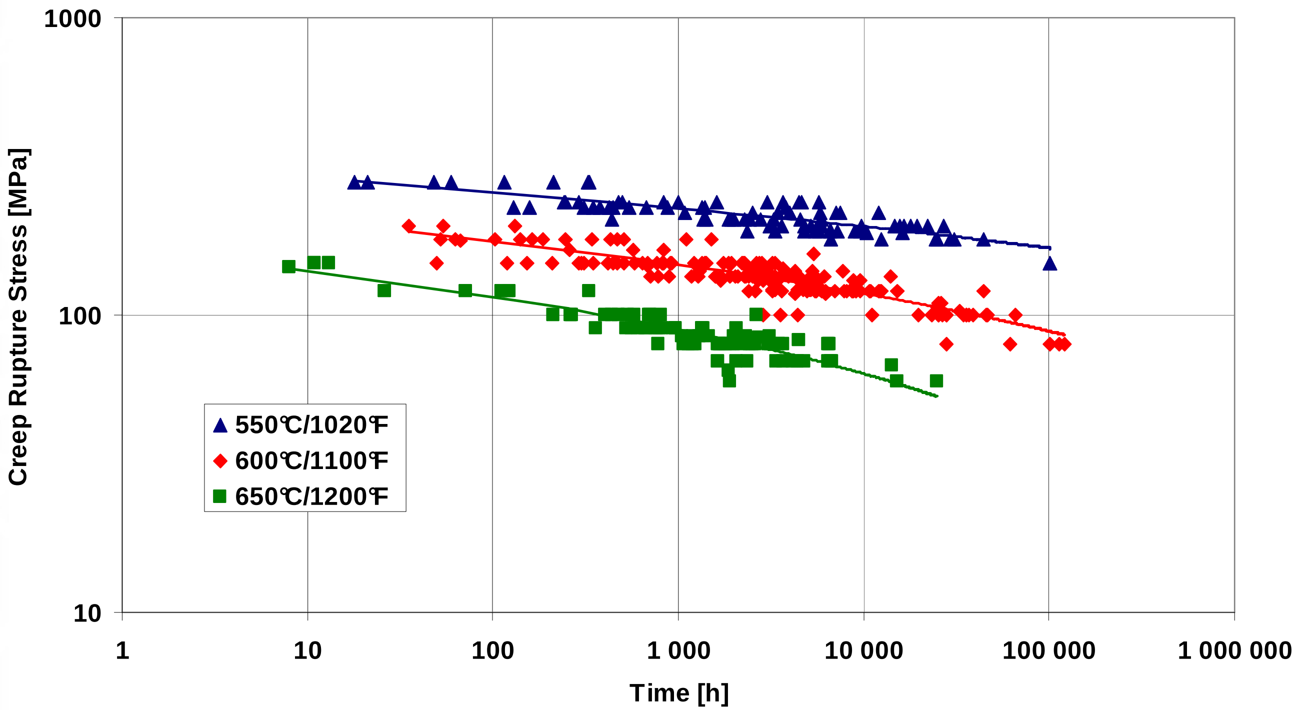
It is very important to well master the heat treatment process to get stable properties even for the whole range of thickness

Mechanical Properties at Elevated Temperature on V&M Products in T/P91





Creep tests: V&M data package



More than 4 millions hours of test, with individual tests longer than 100 000h
Based on tests from V&M industrial products

Non Destructive Tests:
a way to increase reliability of T/P91 products

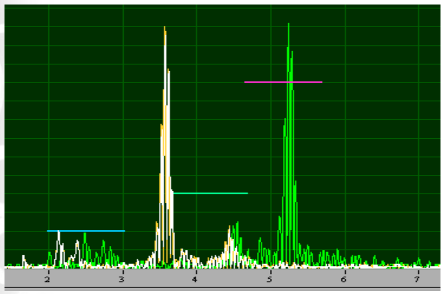
Non Destructive Test:
what is requested by the standards ?

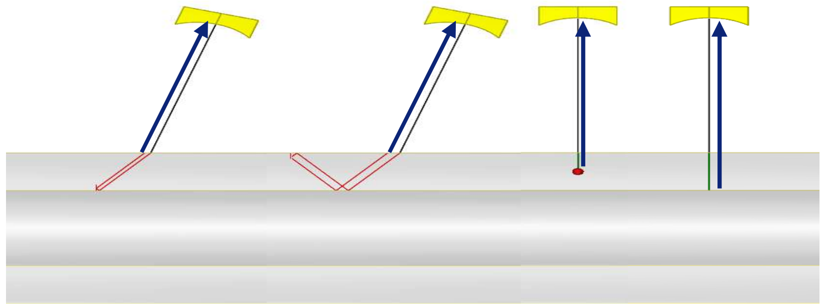
ASTM A 213 / A 335 T/P91	EN10216-2 TC2 X10CrMoVNb9-1
Hydrostatic test *OR* Non Destructive Electric Test: *E 213 Ultrasonic examination* *or* *E 309 Eddy current* *or* *E570 Flux leakage*	Leak tightness test : *Hydrostatic test* *or* *Electromagnetic test EN10246-1* *(Eddy current or Flux leakage)* AND Ultrasonic examination

V&M strategy for NDT

- **The V&M NDT concept ensure:**
- **NDT adapted to the product and the production process for an optimal defect detection**
- **Full length NDT of all tubes and pipes**
- **Automatic verification of Pipe Dimensions**
- **Grade verification and Full Traceability**

Ultrasonic Test: essential for T/P91 to avoid rolling defects and cracks





- **Detection of :**

  Internal & External defects

  Longitudinal & transverse defects

  Lamination

- **WT measurement along the full length**

Other Non Destructive tests

- **Eddy Current complementary to UT for OD up to 180mm**
  - **To check the tube tightness**
  - **Thanks to multi-frequency EC also detects transverse or short longitudinal defects**
- **Positive Material Identification (spectrotest) to check the grade**
- *Magnetic Particle Inspection for large OD pipes or headers: expensive because it requests a very fine surface preparation*
- *Hydro-test: possible but really not necessary*

Non Destructive Tests mainly applied by V&M for T/P91

OD < 180mm

- Eddy current: Multi-frequency E.C
- Ultra Sonic Test (UT) to check:
  - longitudinal defects
  - Wall thickness
- PMI: to check the grade

OD > 180 mm

- Ultra Sonic Test (UT) to check:
  - Longitudinal defects
  - Transverse defects
  - Lamination
  - Wall thickness
- PMI: to check the grade

Focus on Hardness

Hardness Requirement in Standards

- New requirements on hardness for T/P91

A213/A213M – 10

TABLE 4 Tensile and Hardness Requirements

T91	190 to 250 HBW/ 196 to 265 HV

9.2.2 Brinell, Vickers, or Rockwell hardness tests shall be made on specimens from two tubes from each lot. See 14.2.

A335/A335M – 10a

9. Tensile and Hardness Requirements

9.1 The tensile properties of the material shall conform to the requirements prescribed in Table 3.

9.2 Table 4 lists elongation requirements.

9.3 Pipe of Grade P91 shall have a hardness inclusively in the range 190 to 250 HBW/196 to 265 HV [91 HRB to 25 HRC]. Pipe of Grades P92, P122, and P36 shall have a hardness not exceeding 250 HBW/265 HV [25 HRC].

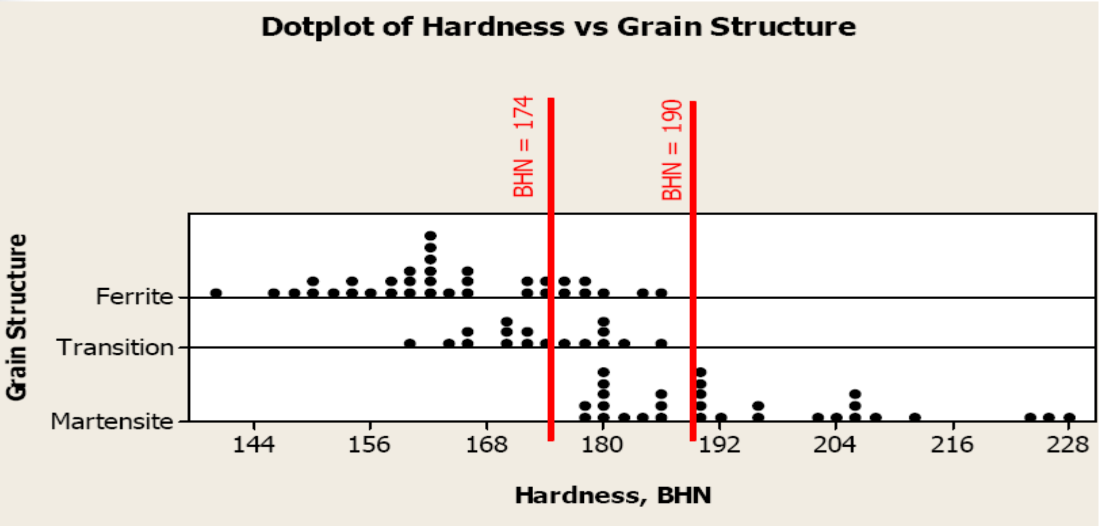
14.3.7 For pipe of Grades P24, P91, P92, P122, P911, and P36, Brinell, Vickers, or Rockwell hardness tests shall be made on a specimen from each lot.

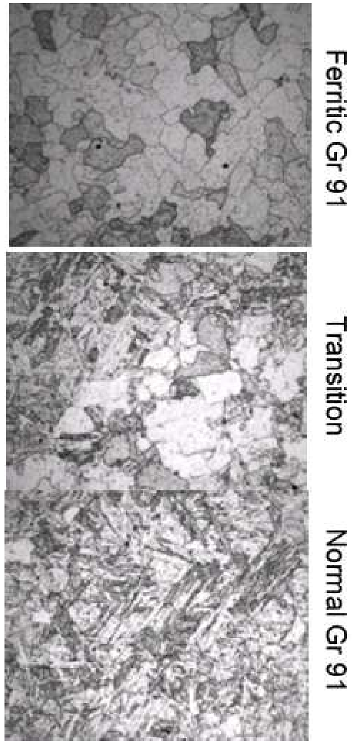
Where is this requirement coming from?

- Further to problems observed on 91 made components in service in USA an action plan has been launched in order to determine easily the root causes and define criteria

- Field Hardness testing of Grade 91 with portable devices has been determined as method linked with microstructural analysis on replicas. (10 000 Hardness test data points, 7 different units, 6 different fabrication shops, 3 different installation contractors,…)

Link with the Microstructure

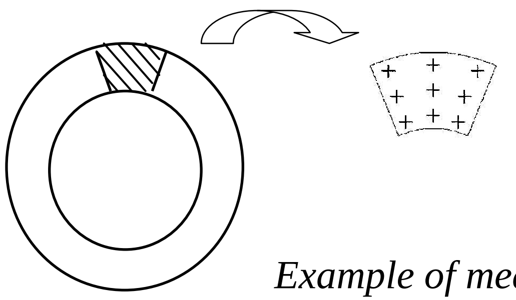




- The final structure will consist in **Tempered Martensite**
- A minimum hardness of **190HB** is considered as a reliable indication to get tempered martensitic structure without ferrite

How to Measure Hardness on Tubes and Pipes ?

- The hardness measurement is not basically well defined and we have to define it with the customer
- Measurement on specimens or measurement on surface with portable device ?



In total,
9 „Readings“
Average value ≥ 190HB

Example of measurement on thick pipes

„Quadrant“ - Testing

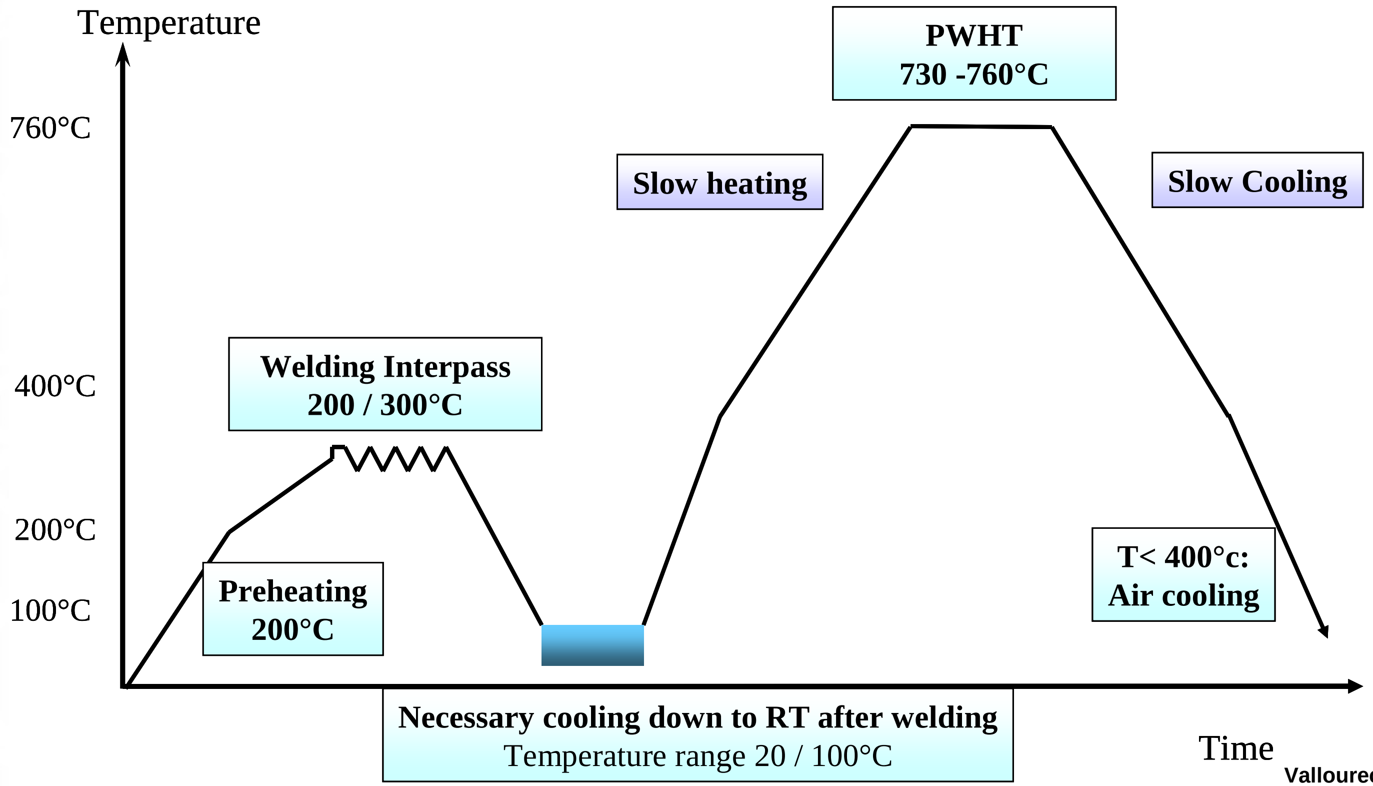
Critical Hardness Measurement on Surface

- Measurement directly on surface (and not on sample) much more critical due to different reasons:
  - Decarburization layer
  - Surface hardening, by machining
  - Accuracy of portable devices
  - Surface preparation
  - Operator experience levels
  - Etc…

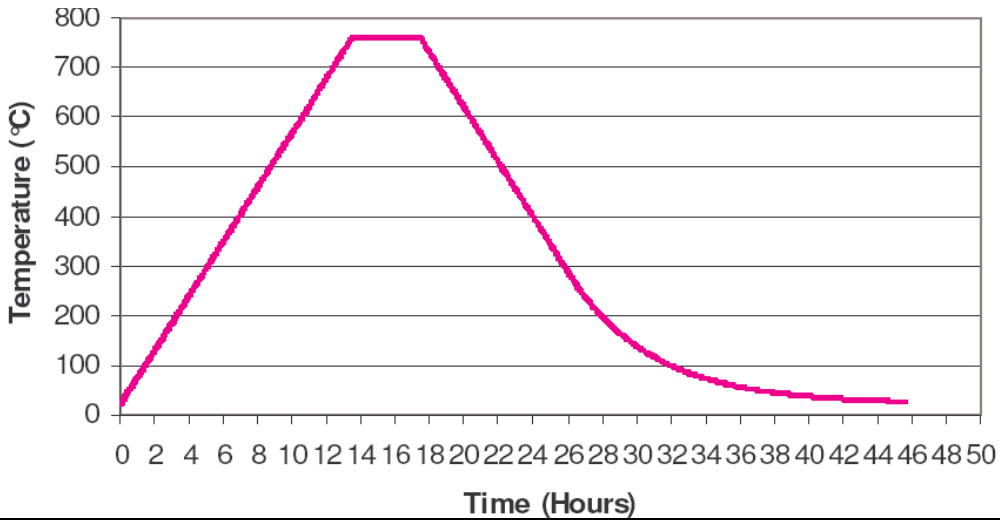
Focus on Welding

- Typical heating cycle
- What is the influence of several PWHT on base material
- What are the risks regarding PWHT

Typical heating cycle for Welding P91

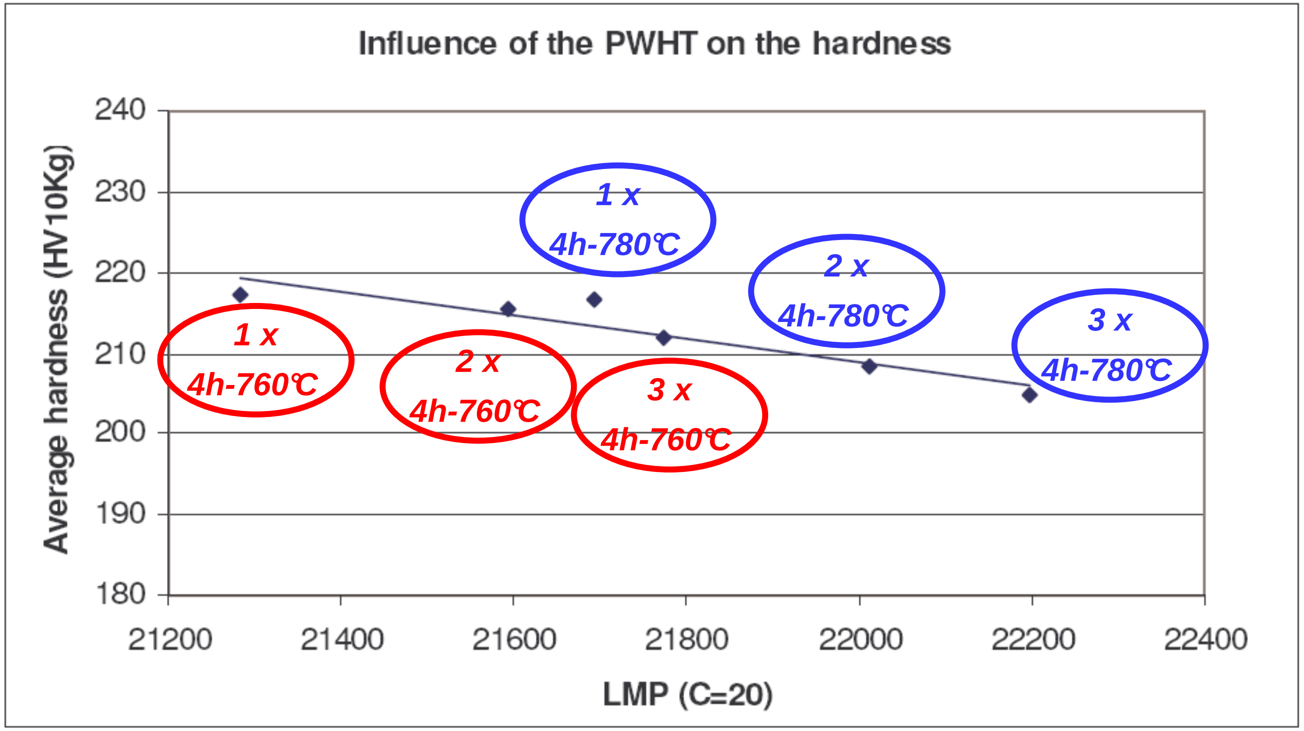


Influence of several PWHT on base material

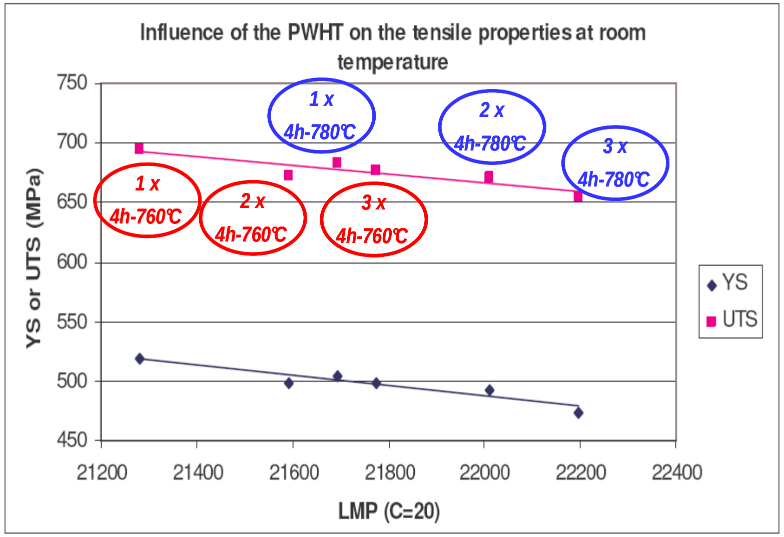


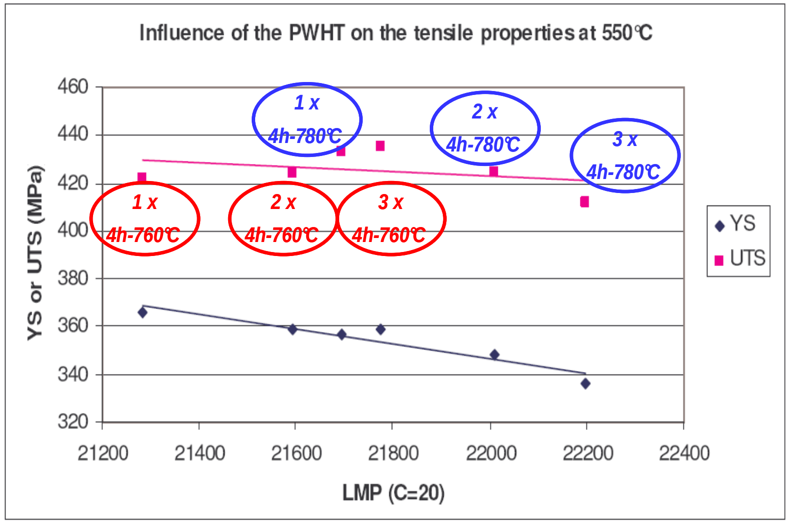
Test condition for 1 cycle				Number of Cycles
Heating rate	Holding temperature	Holding time	Cooling rate	
55°C/h	760°C	4 h	55°C/h	1, 2 or 3
55°C/h	780°C	4 h	55°C/h	1, 2 or 3

Influence of several PWHT on hardness



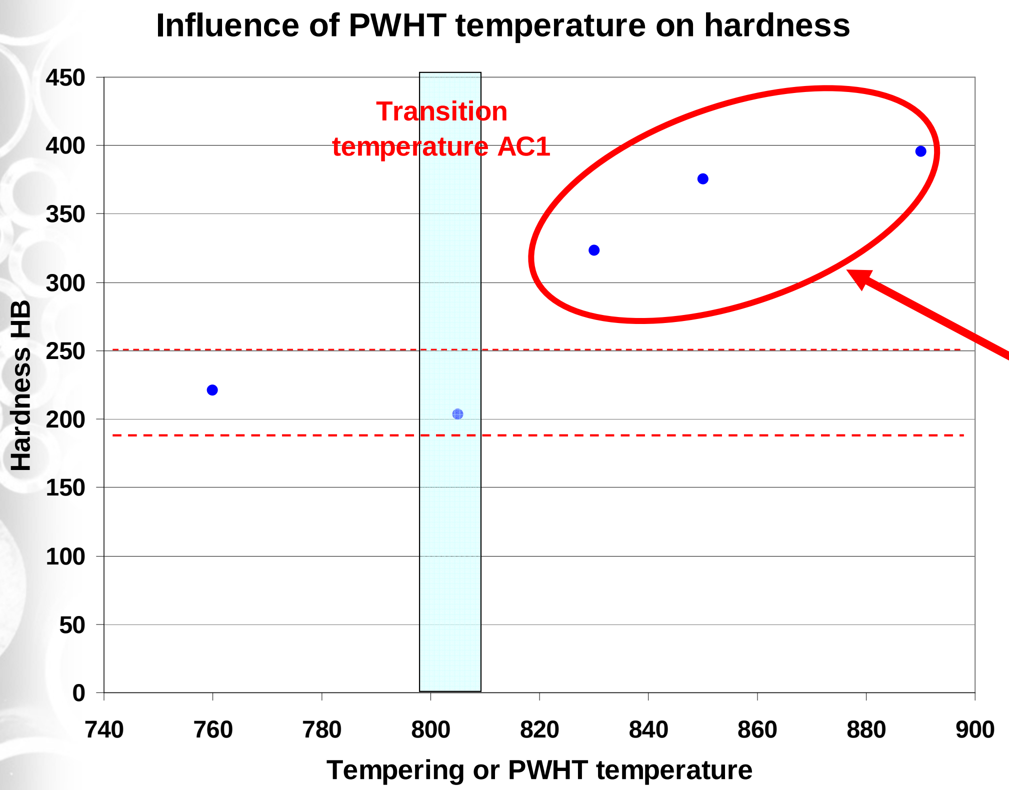
Influence of several PWHT on tensile properties

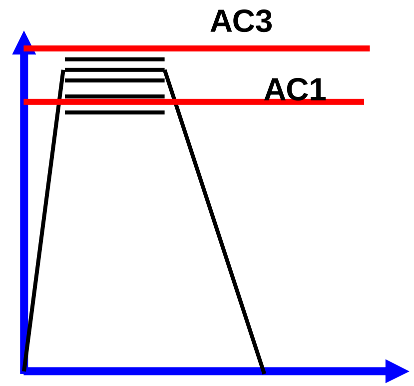




- Several PWHT are possible even if the mechanical properties slightly decrease
- It is not necessary to specify too high value on base material
- But be careful with too high PWHT temperature

What are the risks regarding PWHT: Overheating

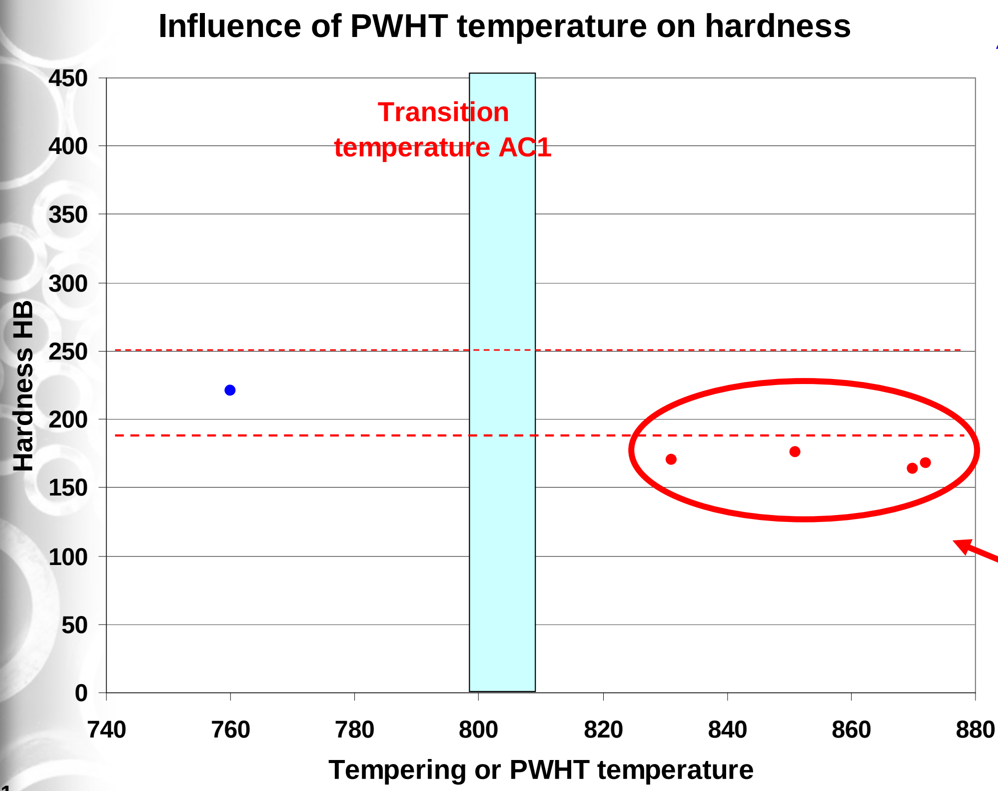


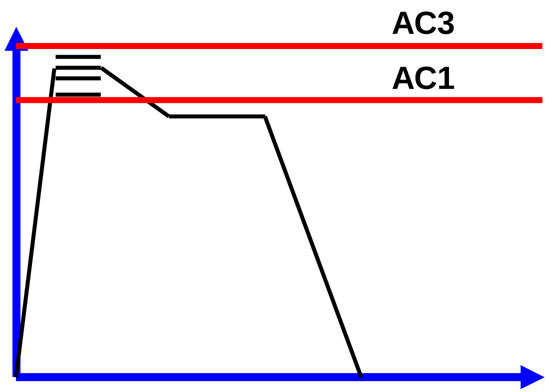


«Fresh» un-tempered martensite

Risk of cracks

Short over-heating during PWHT



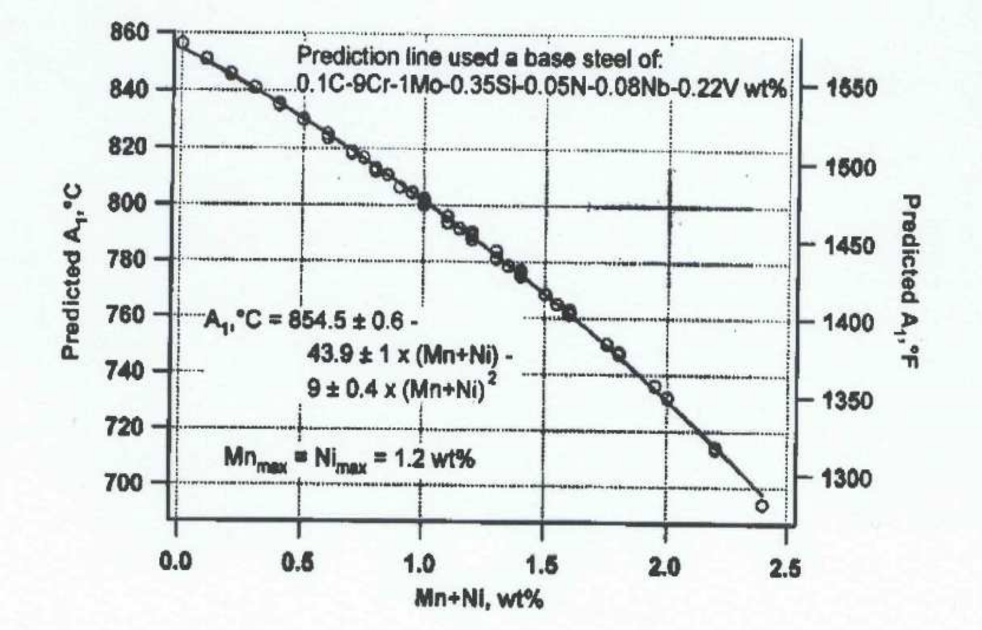


Short over-heating (5 – 30mn) during PWHT at 760°C

Too low hardness:

Risk of transformation into ferrite

Influence of Chemical composition on AC1



- ***Be careful !***
- ***AC1 is strongly influenced by Ni + Mn content***
- ***Take into account the chemical composition of the consumable***

Conclusion

- Thanks to a successful experience of 20 years in grade 91, V&M has developed the production and process control to fulfill the market evolution:
  - High level of quality to get reliable products (creep qualification, NDT…).
  - Broad dimensional range to supply the specific sizes of super critical boilers.
  - Large quantity increase.
- Even if T/P91 is used in most of the power plants in the world, the experience feed back has demonstrated that damage could occur if manufacturing is not performed in proper way.
- Heat treatment and PWHT have a direct influence on microstructure and long term creep properties.
- ASTM has recently introduced a minimum hardness requirement. It is considered as a reliable indicator to get the proper tempered martensitic microstructure on the product.
- Hardness measurement on sample in laboratory is more representative of the material properties than surface measurement with portative device.
- Temperature of PWHT has to be carefully defined and mastered, taking into account the chemistry of the consumable.

BACK


Coal-fired power station/Werdohl Elverlingsen/Germany

Global Welding Solutions

Welding of P91

Dr. Herbert Heuser
Böhler Welding Group; Hamm, Germany

Amitabha Bhattacharya
Bohler Welding Group India

Plant Hamm

Böhler Schweisstechnik Deutschland GmbH

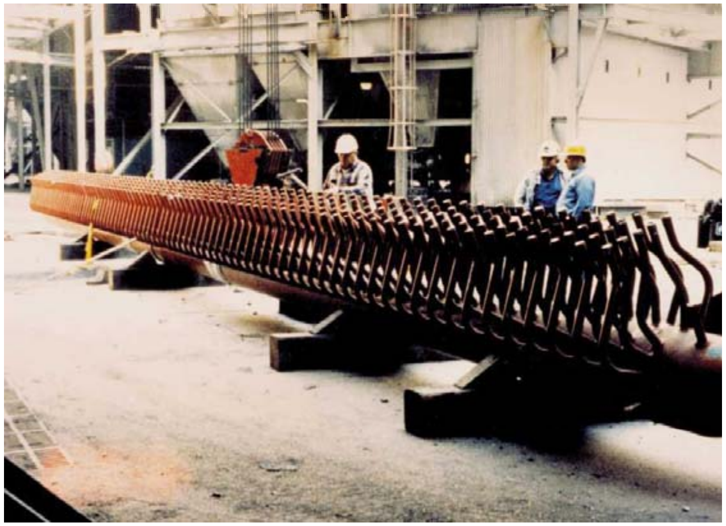
Content

- Introduction
- Requirements on Filler metal
- Optimal welding parameter and heat cycle
- Welding practice
- Filler metal for USC power plants

Tendency of development of the main steam parameters for fossil fired Power plants

	Japan	USA	Europe
today	605°C / 613°C 25 MPa	593°C 27 MPa	600°C / 605°C 28-30 MPa
Near future	630°C 25 MPa	620°C/ 28 MPa (650°C)	600°C / 625°C 28- 30 MPa
Target 2014/15	~ 700°C 35 MPa	760°C 35 MPa	700°C / 720°C 35 MPa

T/P91 (X10CrMoVNb9-1)
A new steel ?



Main steam collector Power Plant Dayton Power/USA

First application P91 – 1989

Pipe delivered by Mannesmann

Filler metal deliver by Böhler (Thyssen) Welding

Today operation time >180. 000 hours

First new Power Plant in Europe with P91 (X10CrMoVNb9-1)

First application: 1992

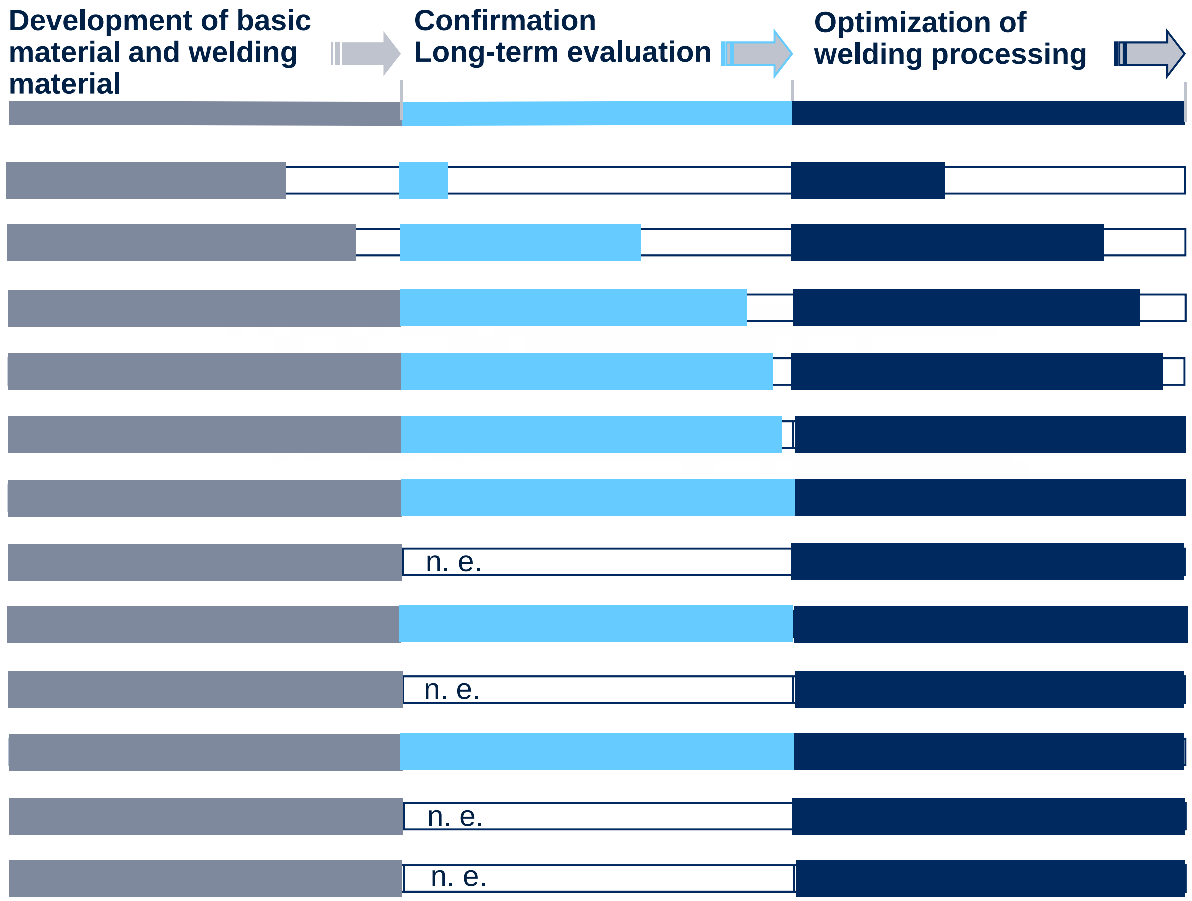
Start up: 1994

Main steam system

Thick-walled SMAW joint of a P91 steam pipe

The Development of Matching Filler Metals

First use	Base material
2007	Super 304 H, HR3C, (347 HFG), Alloy 617
2007	VM12
(1997) 2007	X10CrWMoVNb9-2 (P92)
2000	7CrMoVTiB10-10 (P24)
2000	X11CrMoWVNb9-1-1 (E911)
1990	X10CrMoVNb9-1 (P91)
1970	WB36
1965	X20CrMoV12-1
1960	14MoV6-3
1940	10CrMo9-10
1940	13CrMo4-4
1930	15Mo3



Working in Partnership

TNO
(Netherlands Organisation for Applied Scientific Research)

BWI
(Belgian Welding Institute)

Stahlinstitut VDEh
(Verein deutscher Eisenhüttenleute)

FDBR
(Fachverband Dampfkessel-, Behälter- und Rohrleitungsbau)

Institut für Fertigungs-technik (Universität Graz/A)

phoenix union thermanit

VALLOUREC & MANNESMANN TUBES

SZMF – Salzgitter Mannesmann Forschungsinstitut

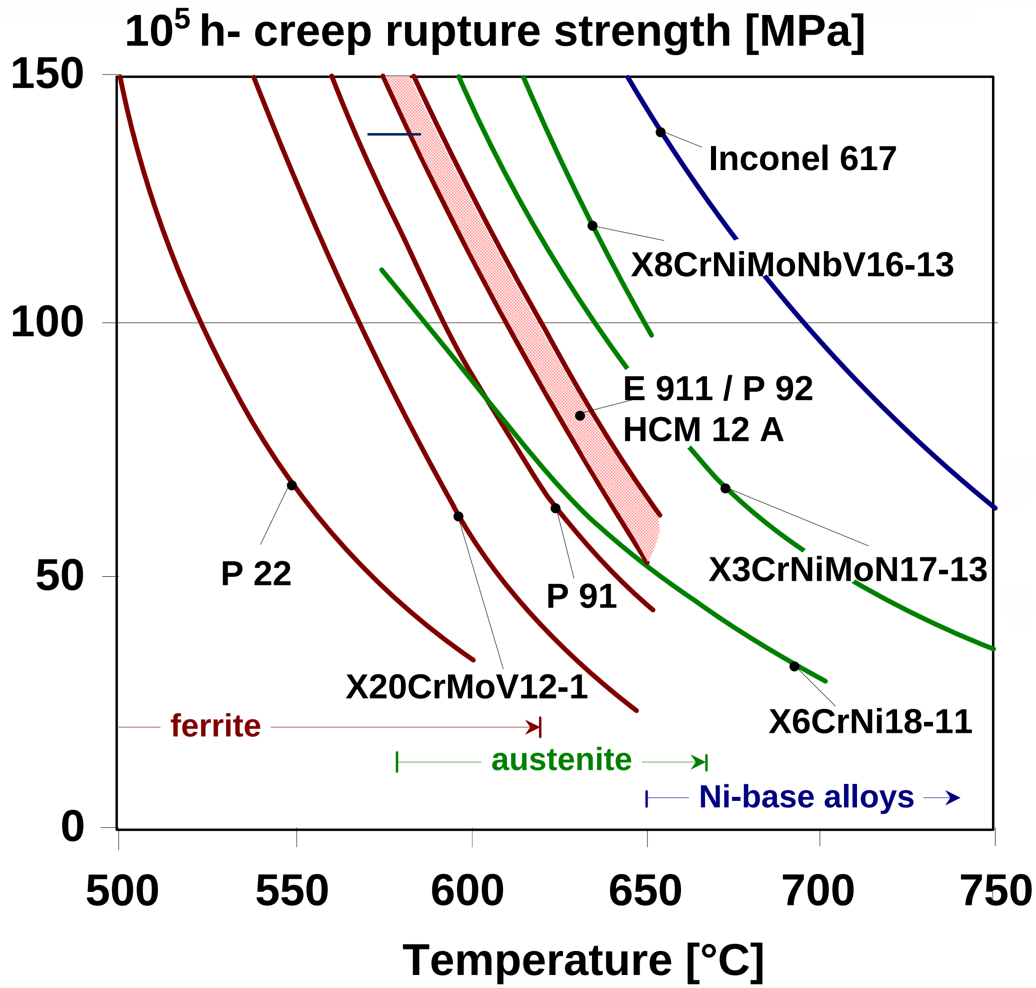
Siempelkamp Prüfgesellschaft, Dresden

Materialprüfungsanstalt Universität Stuttgart

Institut für Werkstoffkunde Technische Universität Darmstadt

Fraunhofer Institut Freiburg

Böhler Welding GROUP



Pipe- / Tube- steels
for superheaters and reheaters in fossil fired power plants

Designation		C	Cr	Ni	Mo	V	W	Nb	others	Service temperature [°C] [1]
X10CrMoVNb 9-1 1.4903 (P 91)	min. max.	0,08 0,12	8,0 9,5	< 0,40	0,85 1,05	0,18 0,25	---	0,06 0,10	N 0,030 0,070	≤ 585
X11CrMoWVNb 9-1-1 1.4905 (E 911)	min. max.	0,09 0,13	8,50 9,50	0,10 0,40	0,90 1,10	0,18 0,25	0,90 1,10	0,06 0,10	N 0,05 0,09	≤ 625
P 92 (Nf 616)	min. max.	0,07 0,13	8,5 9,5	< 0,40	0,30 0,60	0,15 0,25	1,5 2,0	0,04 0,09	N 0,03 0,07 B 0,001 0,006	≤ 625

[1] constructive obvious service temperature limit in power stations

Chemical composition of new martensitic steels for power plants

Chemical composition of all weld metal

	C	Si	Mn	P	S	Cr	Mo	Ni	V	Nb	N	Cu	Al
min.	0.08	-	-	-	-	8.0	0.80	-	0.15	0.04	0.030	≤	≤
max.	0.13	0.30	1.0	0.010	0.010	9.5	1.10	1.0	0.25	0.08	0.070	0.25	0.04

Mn + Ni < 1.5 %; tendency to < 1.2%

A_{C1} > 770 °C

Mechanical properties at RT:

after PWHT at 760 °C (1,400 °F) / 2 h;

YS MPa (KSi)	TS MPa (KSi)	Elongation %	CVN J (FT-LB)
530 (77)	620 (90)	≥ 17	≥ 41 (30)

Requirements for P 91 all weld metal

Chemical composition; wire and all weld metal [wt-%]

Welding process	Type	Ø [mm]	C	Si	Mn	Cr	Mo	Ni	V	Nb	N
SMAW	Thermanit Chromo 9 V	3,2	0,09	0,23	0,65	9,1	1,0	0,76	0,20	0,06	0,03
GTAW	Thermanit MTS 3	2,4	0,09	0,15	0,43	9,2	1,0	0,75	0,22	0,04	0,03
SAW	Thermanit MTS 3 flux: Marathon 543	3,0	0,09	0,22	0,32	8,7	0,9	0,71	0,22	0,05	0,036

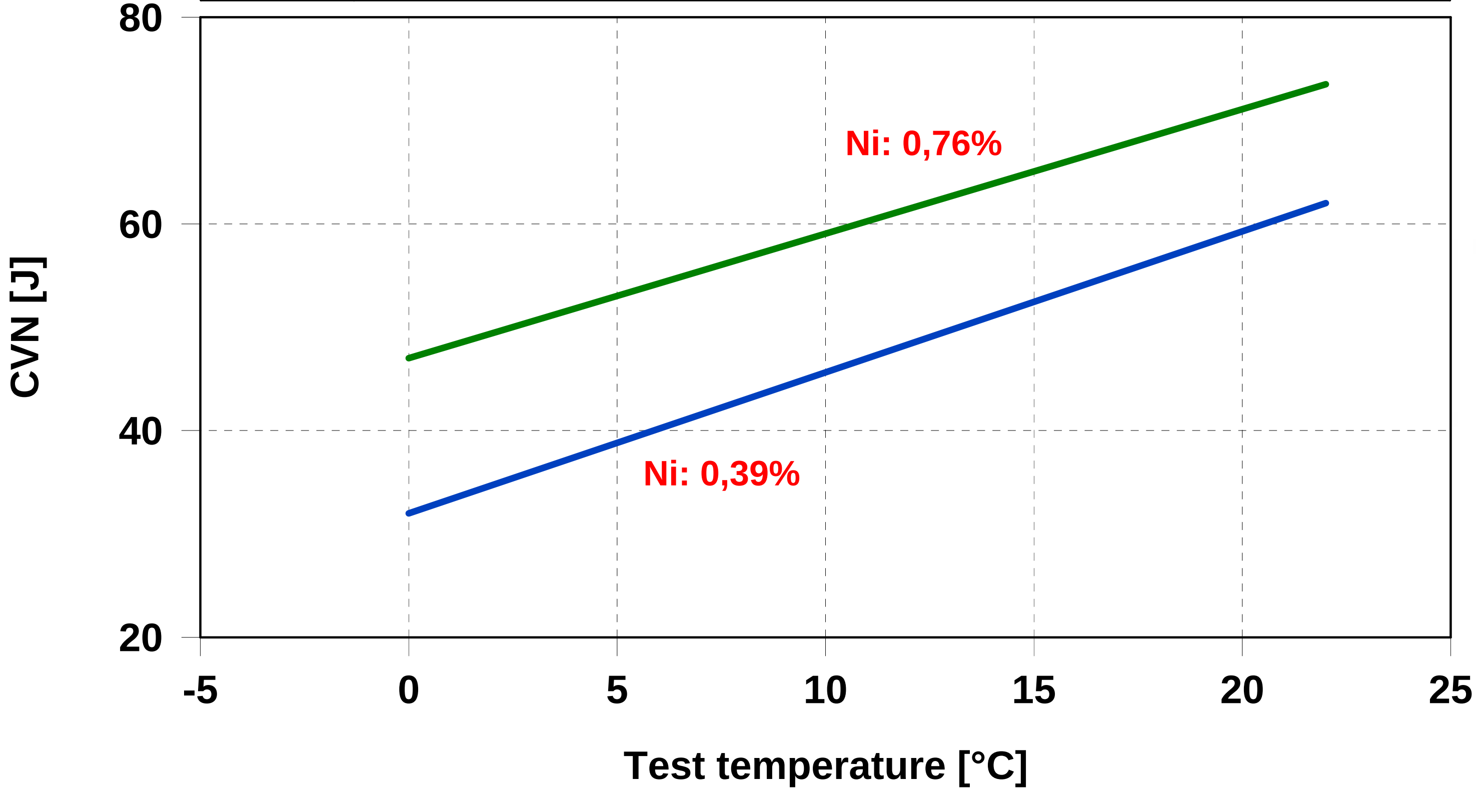
Mechanical properties at + 20°C after PWHT at 760°C/2h

Welding process	Type	Ø [mm]	YS [MPa)	TS [MPa]	Elongation [%]	CVN, ISO-V [J]
SMAW	Thermanit Chromo 9 V	3,2	621	729	19,4	62 67 64
GTAW	Thermanit MTS 3	2,4	669	769	19,8	191 194 250
SAW	Thermanit MTS 3 flux: Marathon 543	3,0	581	738	20,0	65 74 77

Chemical composition and mechanical properties of SMAW, GTAW and SAW filler metals for P91

Chemical composition [weight-%]

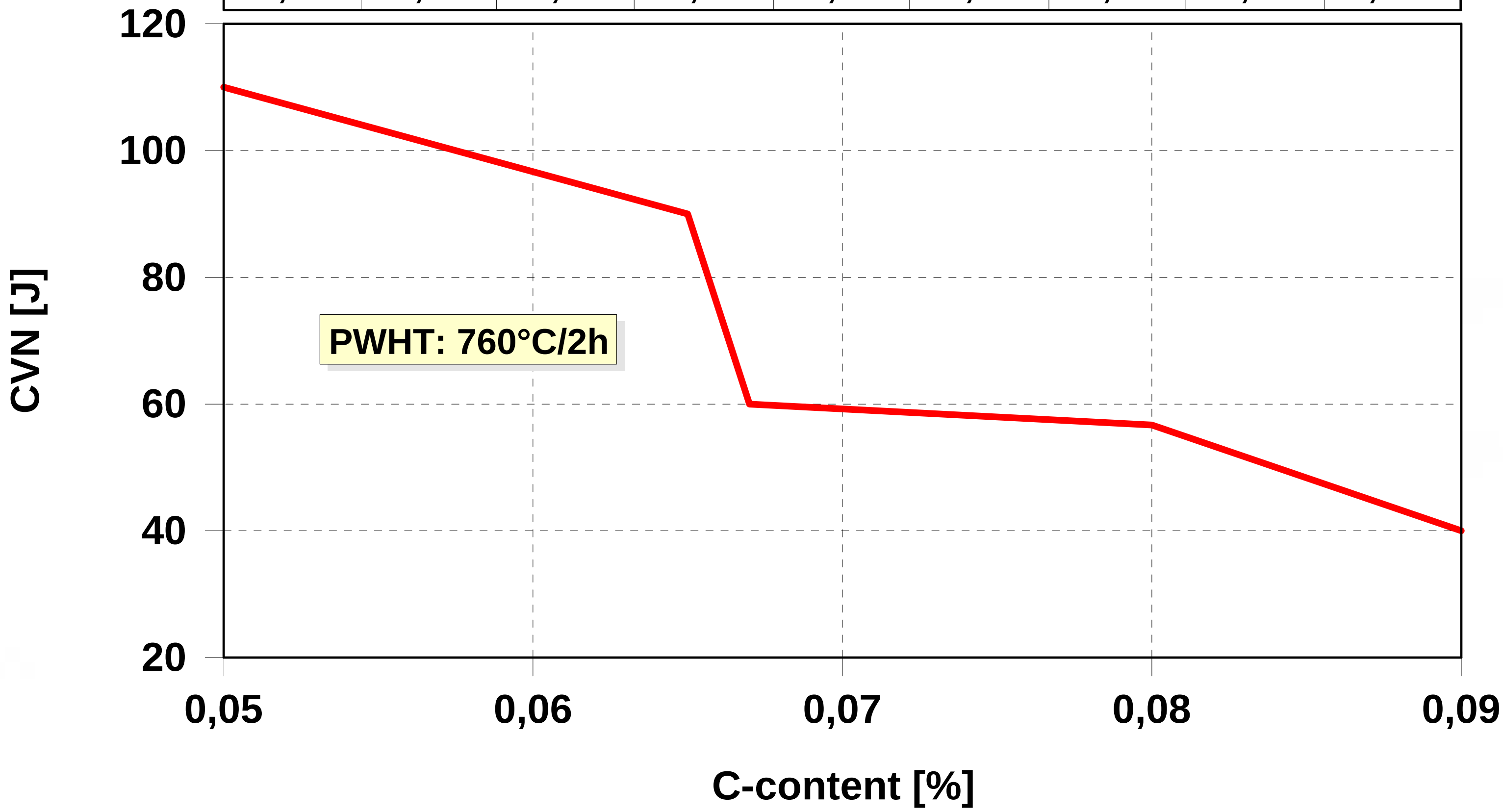
Weld metal	C	Si	Mn	Cr	Mo	Ni	Nb	V	N
No. 1	0,10	0,26	0,68	9,39	1,05	0,39	0,055	0,21	0,032
No. 2	0,10	0,25	0,64	9,05	1,05	0,76	0,054	0,20	0,033



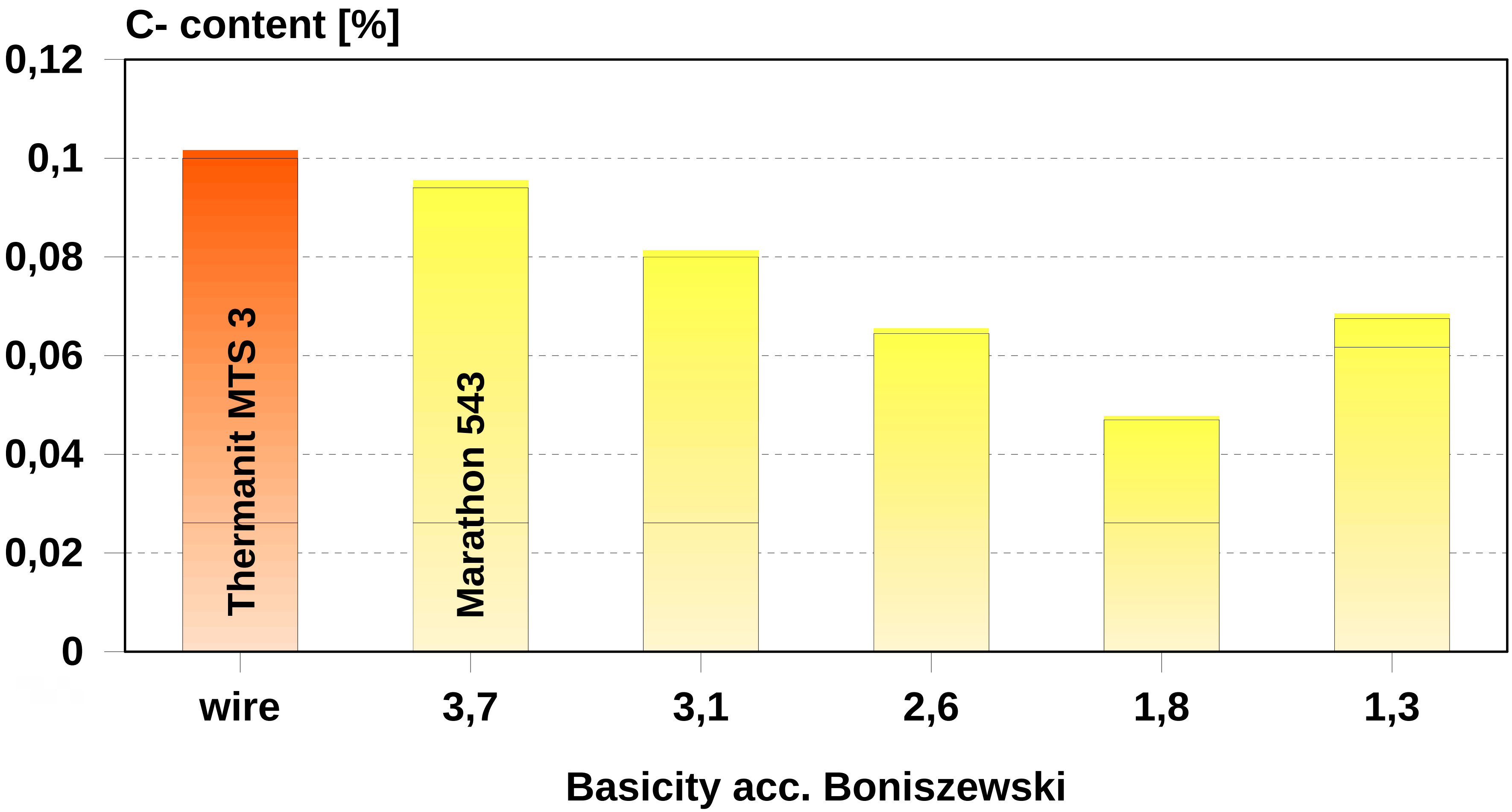
Influence of the Ni-content to the toughness of Thyssen Chromo 9 V

Wire analysis

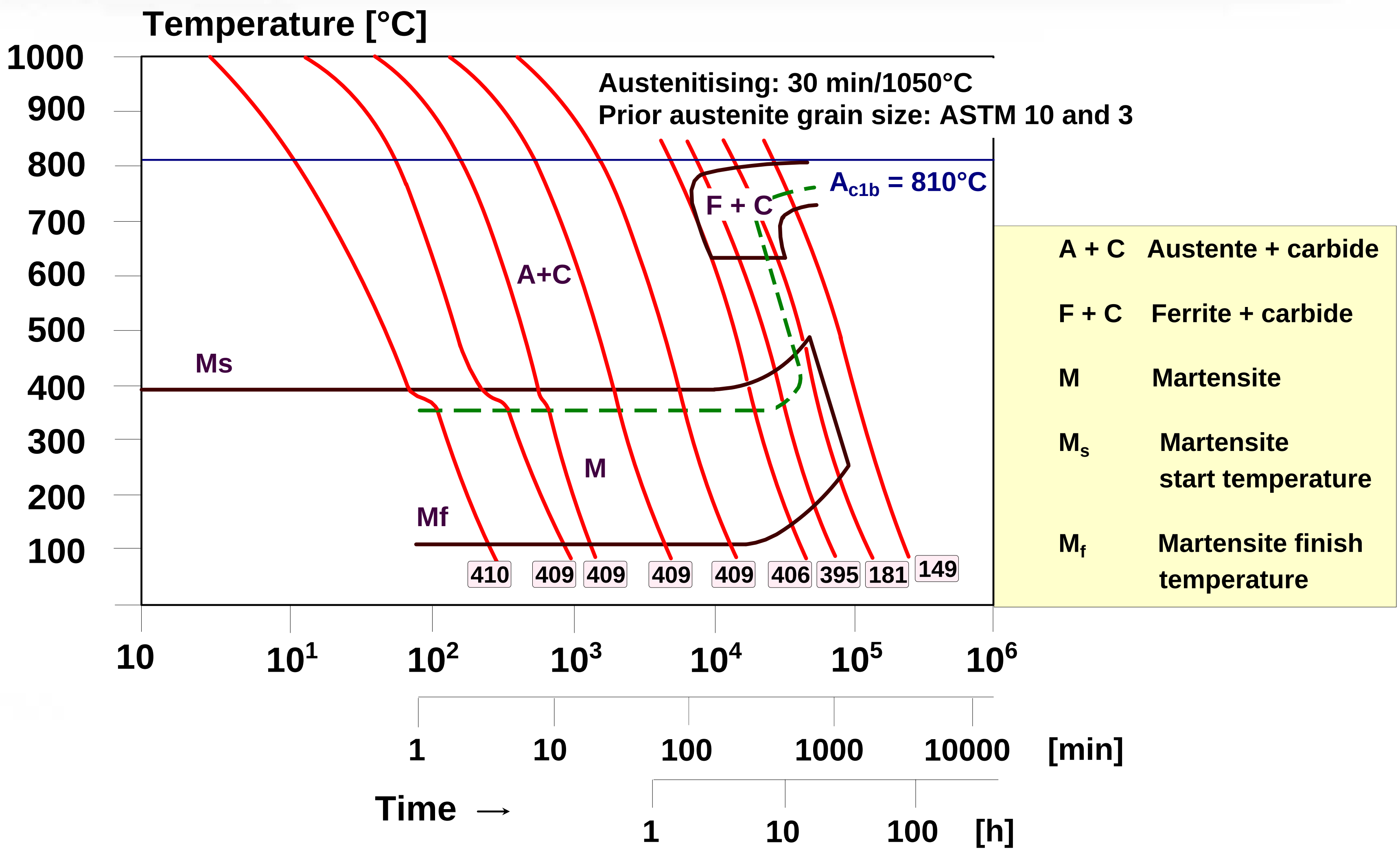
C	Si	Mn	Cr	Mo	Ni	Nb	V	N
0,10	0,16	0,51	9,20	1,03	0,76	0,07	0,22	0,044



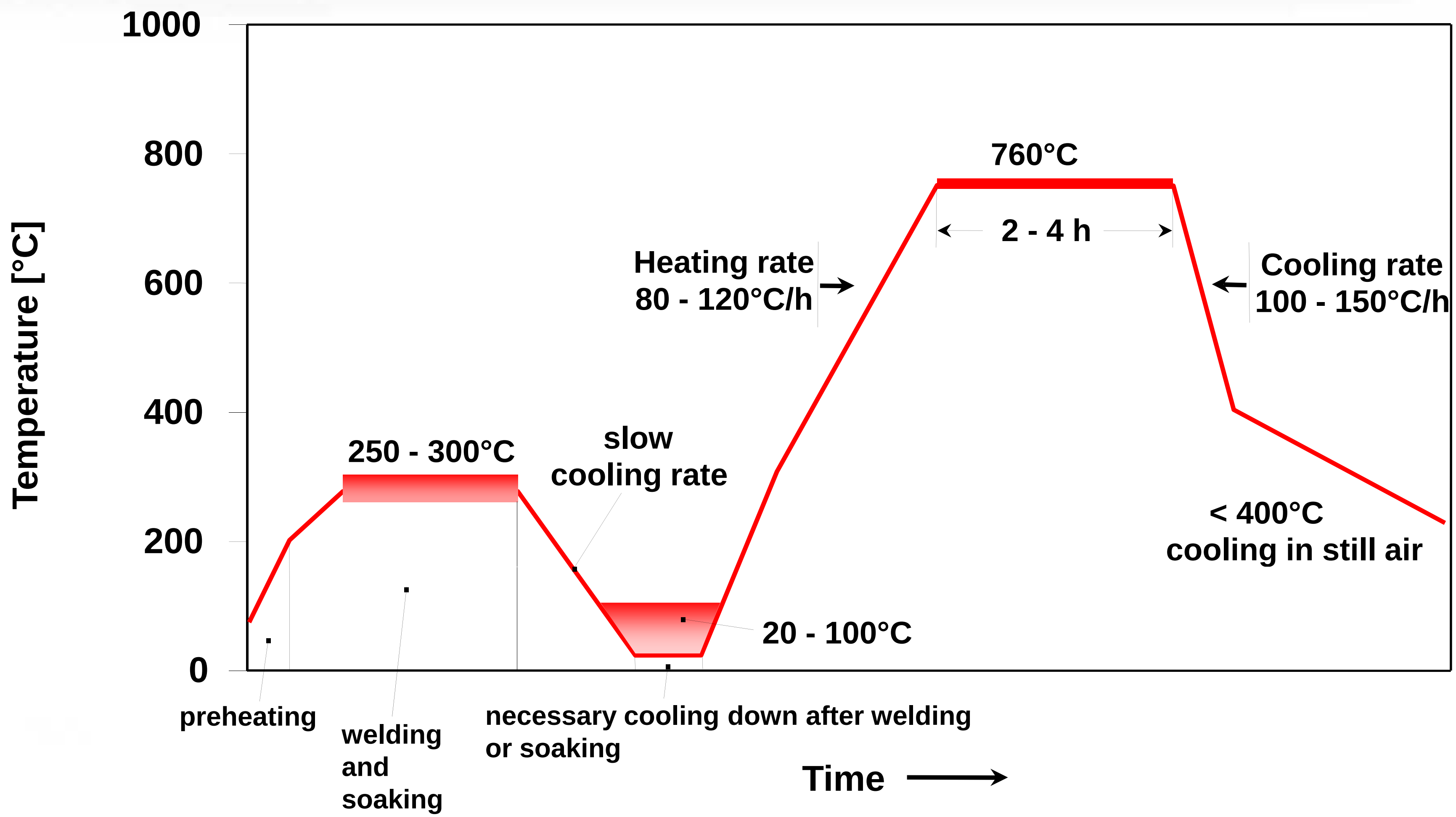
Influence of the C-content to the toughness of Thermanit MTS 3 / Marathon 543



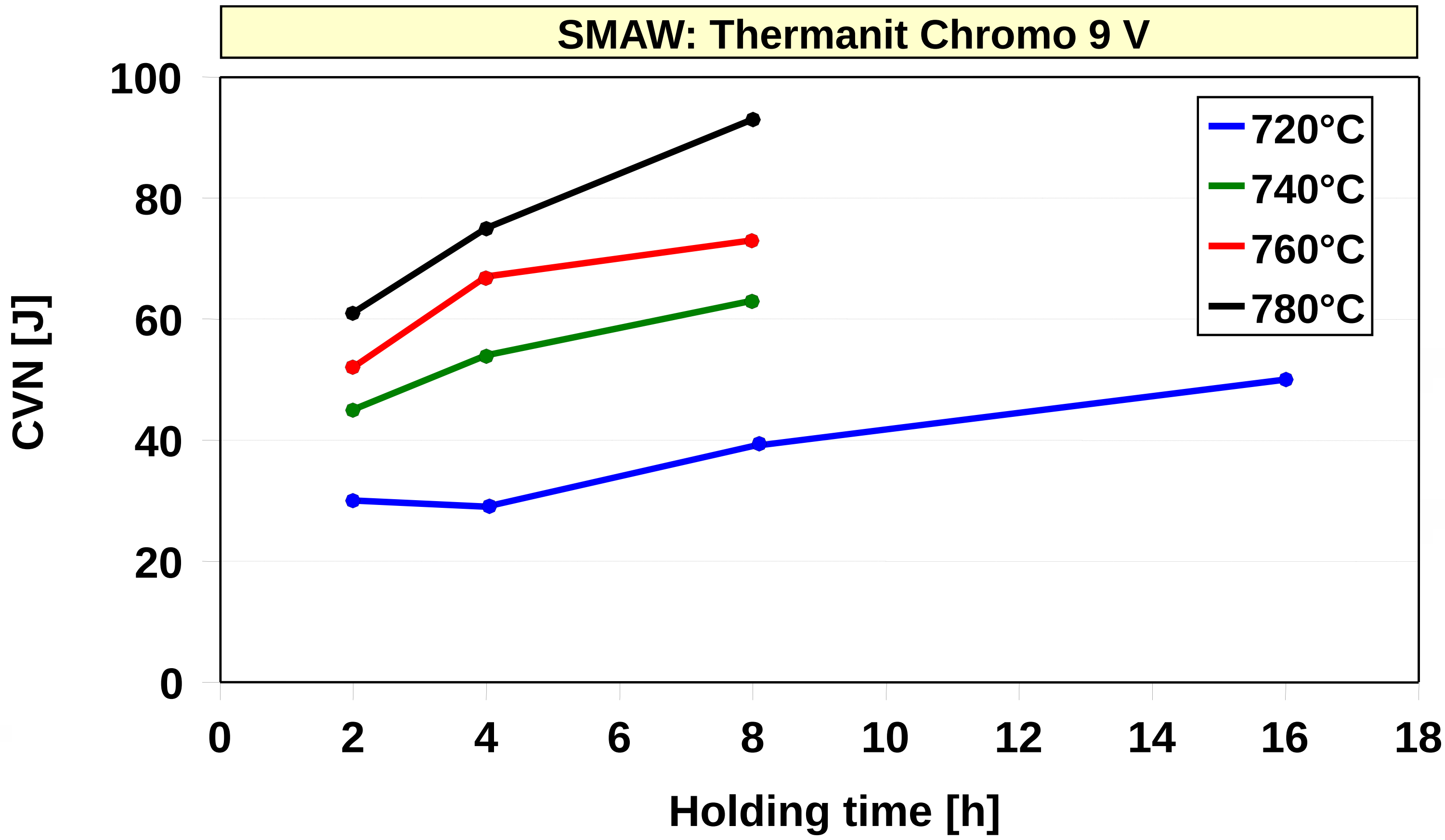
Influence of the flux basicity to the C- burn- out



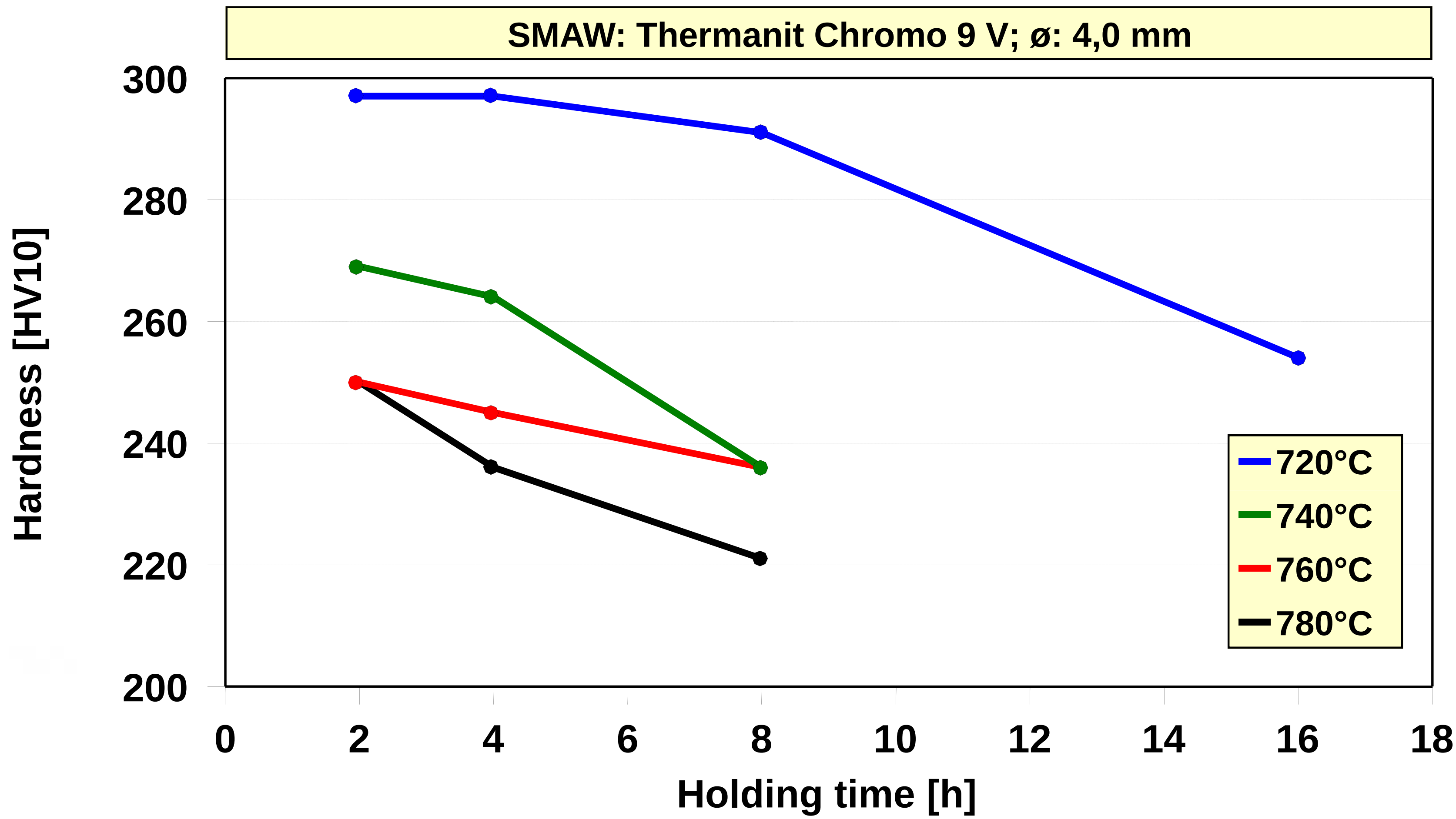
Continous cooling tranformation-diagram of T / P 91 steel



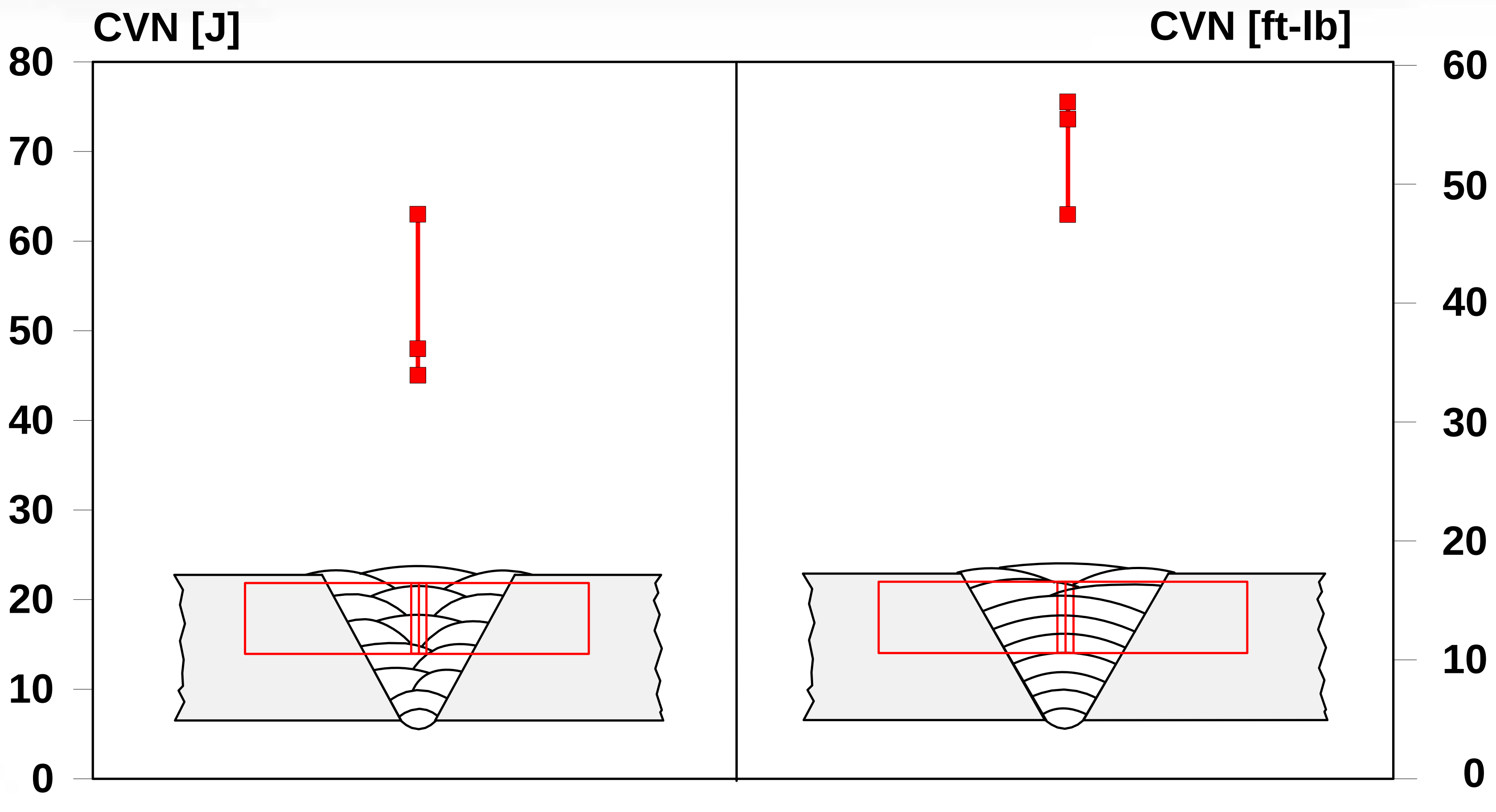
P 91; Heat control during welding and PWHT- condition



Influence of PWHT- conditions
to the toughness of matching filler metal to P91



Influence of the PWHT-conditions (temperature / time) on the hardness at + 20°C



Toughness at + 20°C in relation to the weld build-up (SMAW – all weld metal for P 91)

P91; Control Preheat-, Interpass- and PWHT- Temperature

Endcrater cracks at SMA welds of P91; can be avoid by current sloped down; If not, grinding the end crater

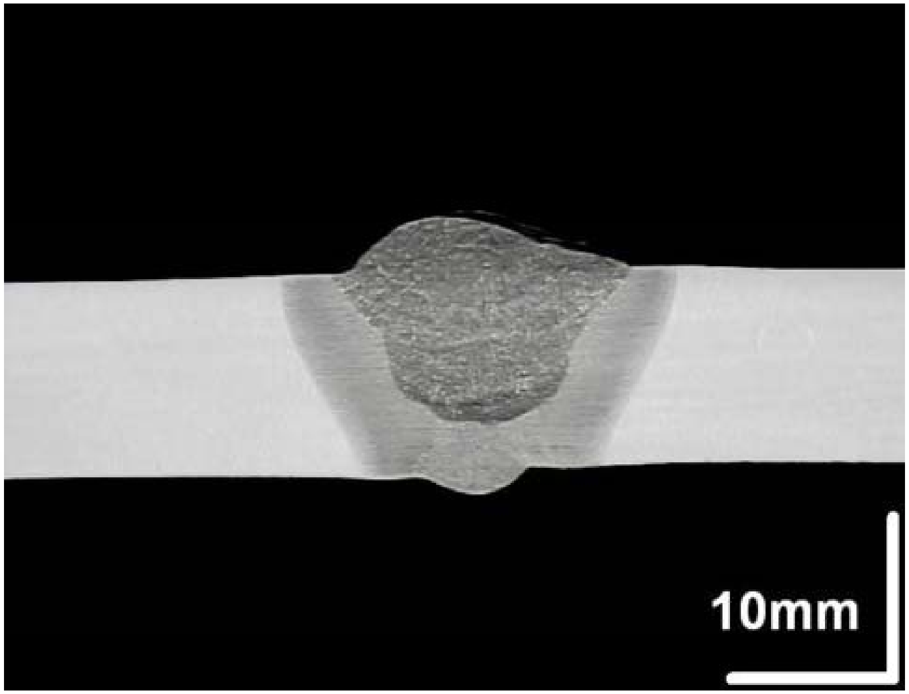
Chemical composition all weld metal for P 91										
C	Si	Mn	P	S	Cr	Mo	Ni	V	Nb	N
0.10	0.21	0.68	0.008	0.008	8.91	1.05	0.81	0.21	0.041	0.041

Mechanical properties all weld metal at RT after quenching + tempering:					
Heat treatment	YS MPa	TS MPa	A4 %	CVN – (ISO-V) J	Hardness HV 10
1050 °C / 30 min. + 760 °C / 2 h	548	701	23	118 / 121 / 117	236
1070 °C / 30 min. + 760 °C / 2 h	548	693	20	127 / 124 / 128	236

Welding parameter SMAW: El-Ø: 4.0 mm; $T_{Preheat}$ = 200 °C; $T_{Interpass}$ = 250 °C; I_S = 170 A

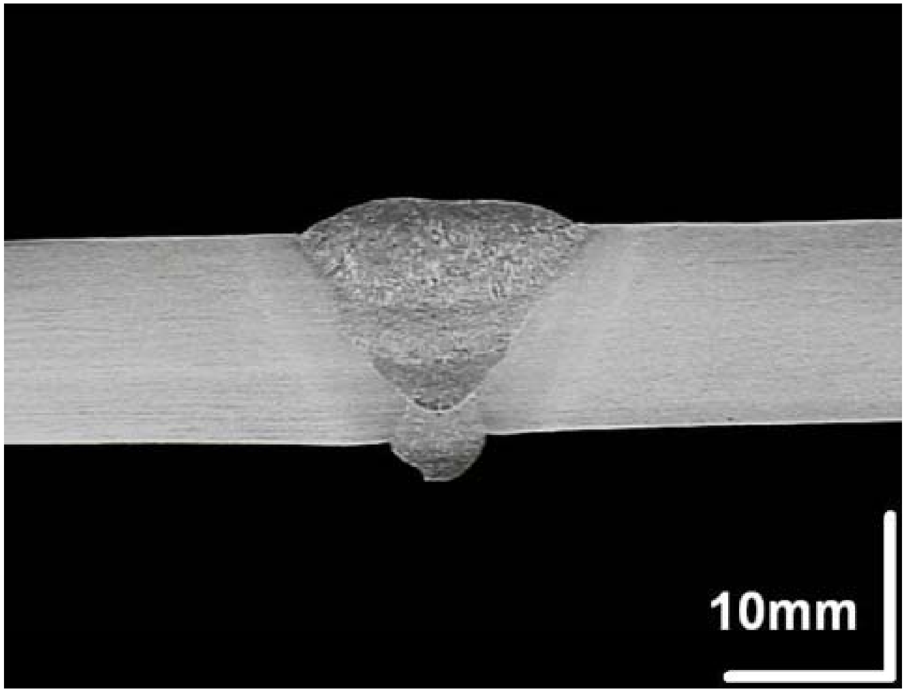
SMA weld metal Thyssen Chromo 9 V quenched + tempered

P91 root electrode for application where purging is not possible



2067

Without PWHT



2068

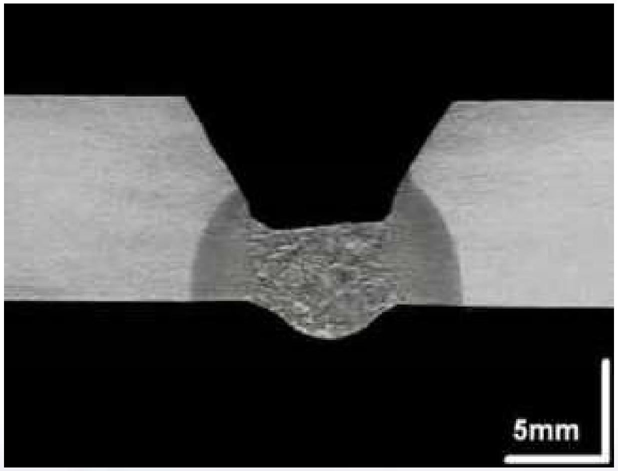
(different locations at the half pipe)

PWHT: 760°C / 2h

Test results at RT (after PWHT):
Ys: 476 MPa; Ts: 663 MPa; Location of fracture: BM
CVN: 40 / 35 / 38 J; Hardness: 254 HV10 max

P91- girth weld; root with Thermanit Chromo T91; vertical up (DC-) (welded at Bechtel)

Thermanit Chromo T91

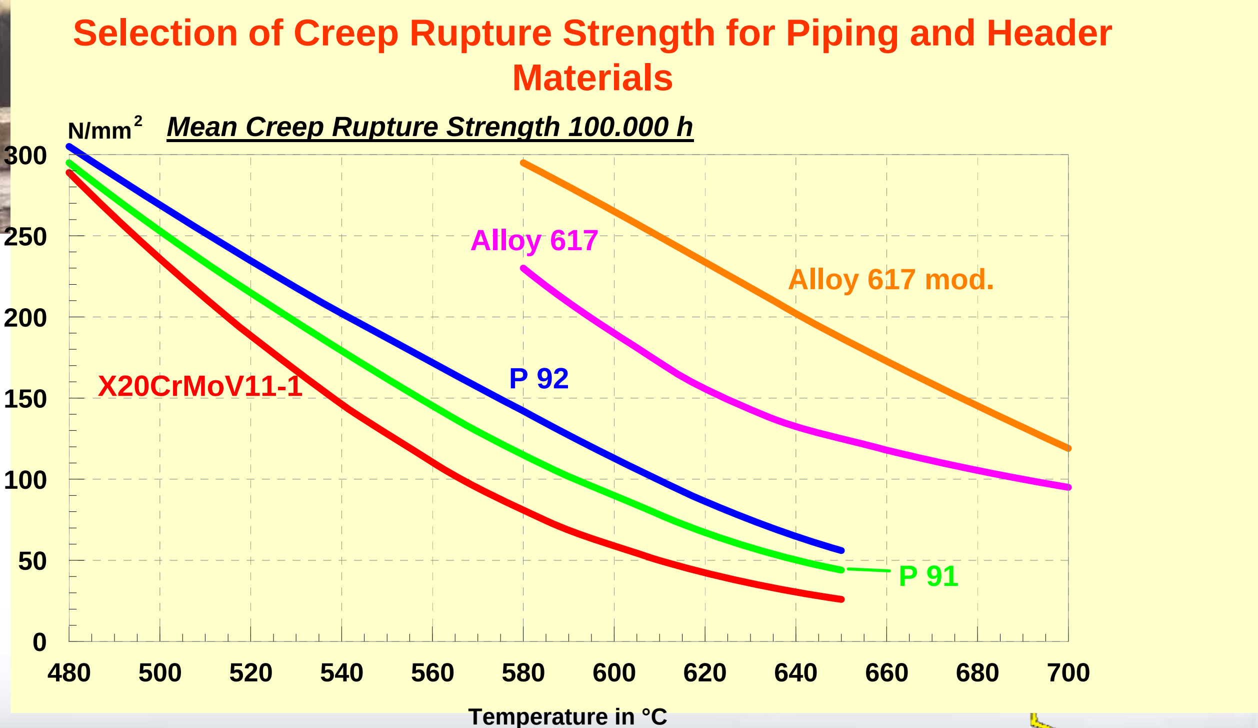


P 91: SMA - root welding

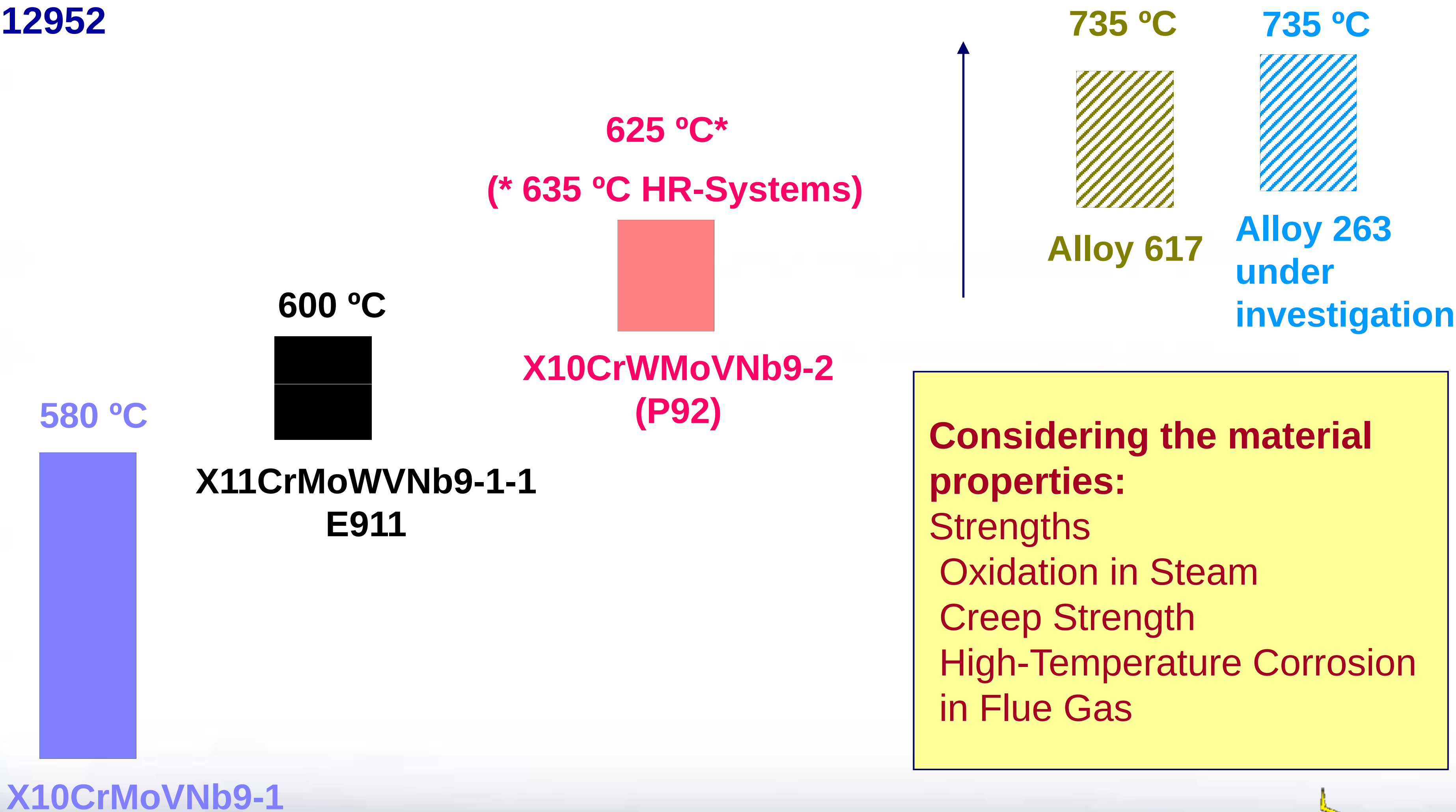
Filler metal for new pipe and tube steels for USC power plants; P92 and VM12-SHC

Materials for Headers and Piping for USC Power Plants

- X20CrMoV11-1
- X10CrMoVNb9-1(P91)
- X11CrMoWVNb9-1-1 (P911/E911)
- X10CrWMoVNb9-2 (P92)
- Alloy 617



Temperature Limits of Headers and Piping Systems used by HPE under the Aspects of Design Temperatures according EN 12952



Considering the material properties:
Strengths
Oxidation in Steam
Creep Strength
High-Temperature Corrosion in Flue Gas

Matching filler metals (FM) for the base metals (BM) P91, P92 and VM12-SHC

Chemical composition all weld metal

BM	FM	C	Si	Mn	Cr	Mo	Ni	V	Nb	W	B	N	Co
P91	SMAW	0,098	0,28	0,51	8,93	1,00	0,33	0,22	0,054	–	–	0,038	–
	FCW	0,10	0,19	0,68	8,85	1,00	0,43	0,21	0,041	–	–	0,046	–
	GTAW	0,098	0,25	0,74	8,81	0,99	0,46	0,19	0,061	–	–	0,030	–
	SAW*	0,085	0,27	0,75	8,72	0,95	0,43	0,18	0,044	–	–	0,039	–
P92	SMAW	0,107	0,23	0,76	8,58	0,45	0,60	0,19	0,044	1,69	0,0050	0,037	–
	FCW	0,092	0,17	0,86	9,31	0,46	0,57	0,21	0,046	1,47	0,0029	0,044	–
	GTAW	0,095	0,25	0,72	8,10	0,41	0,44	0,17	0,056	1,70	0,0020	0,033	–
	SAW*	0,095	0,24	0,81	8,50	0,44	0,53	0,17	0,067	1,74	0,0020	0,044	–
VM12-SHC	SMAW	0,126	0,26	0,63	11,32	0,31	0,83	0,22	0,058	1,39	0,0019	0,058	1,49
	GTAW	0,124	0,40	0,46	11,59	0,30	0,43	0,22	0,060	1,45	0,0030	0,046	1,65

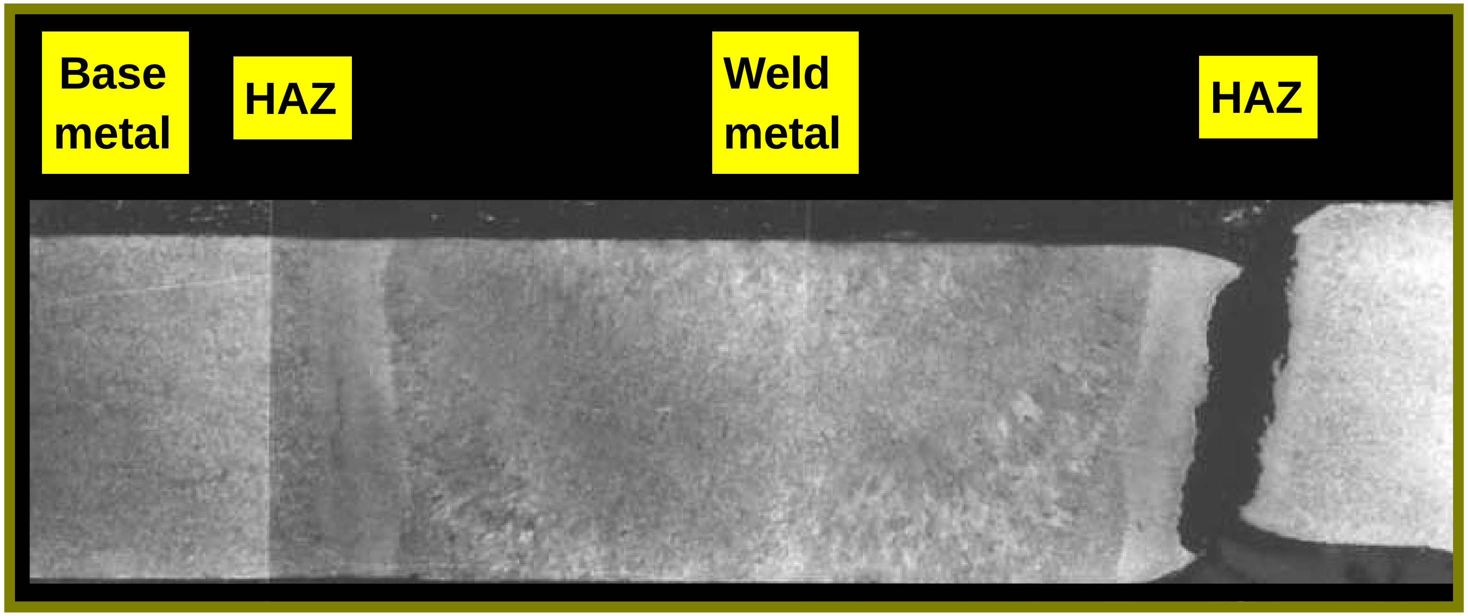
* Flux BB 910 / Marathon 543

Matching filler metals (FM) for the base metals (BM) P91, P92 and VM12-SHC

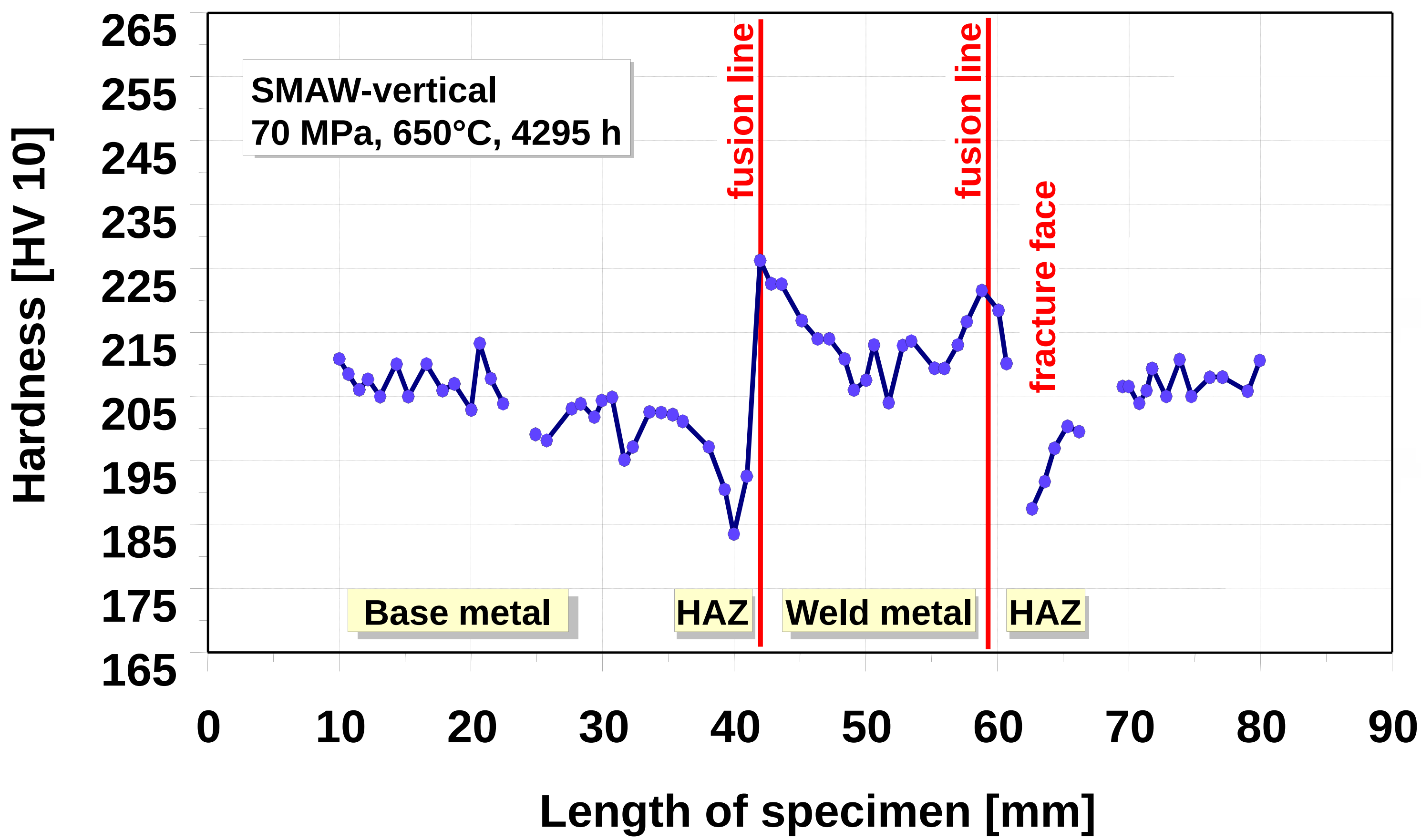
Mechanical properties all weld metal at RT

BM	FM	Ø mm	PWHT °C/h	YS MPa	TS MPa	Elongation %	CVN (ISO-V)	Hardness HV10
P91	SMAW	4,0	760/2	615	740	19,7	70 / 74 / 96	max. 254
	FCW	1,2	760/2	633	761	19,0	36 / 41 / 42	max. 250
	GTAW	2,4	760/2	682	795	16,4	170 / 171 / 182	max. 250
	SAW*	3,2	760/2	593	721	20,0	48 / 64 / 76	max. 245
P92	SMAW	4,0	760/2	647	774	17,8	46 / 47 / 52	max. 250
	FCW	1,2	760/4	637	743	18,2	43 / 50 / 54	max. 250
	GTAW	2,4	760/2	674	781	18,2	135 / 155 / 178	max. 250
	SAW*	3,2	760/4	638	761	19,6	70 / 77 / 80	max. 245
VM12-SHC	SMAW	4,0	770/2	610	792	14,4	42 / 46 / 47	max. 295
	GTAW	2,4	770/2	684	822	18,5	38 / 43 / 47	max. 297

* Flux BB 910 / Marathon 543



Fracture location of crossweld sample;
P911 / SMAW Thermanit MTS 616; 650°C, 70 MPa, 4295 hrs



Hardness profiles of creep samples; welded joint (P92 / Thermanit MTS 616)

Requirement of time limit between welding and PWHT of the martensitic steels P91, P92 und VM12-SHC:

NO, if adherence of the following conditions:

- **”stress free” storage and stress free transport**
- **Avoidance of extreme environmental influence (high air moisture, sea air atmosphere)**

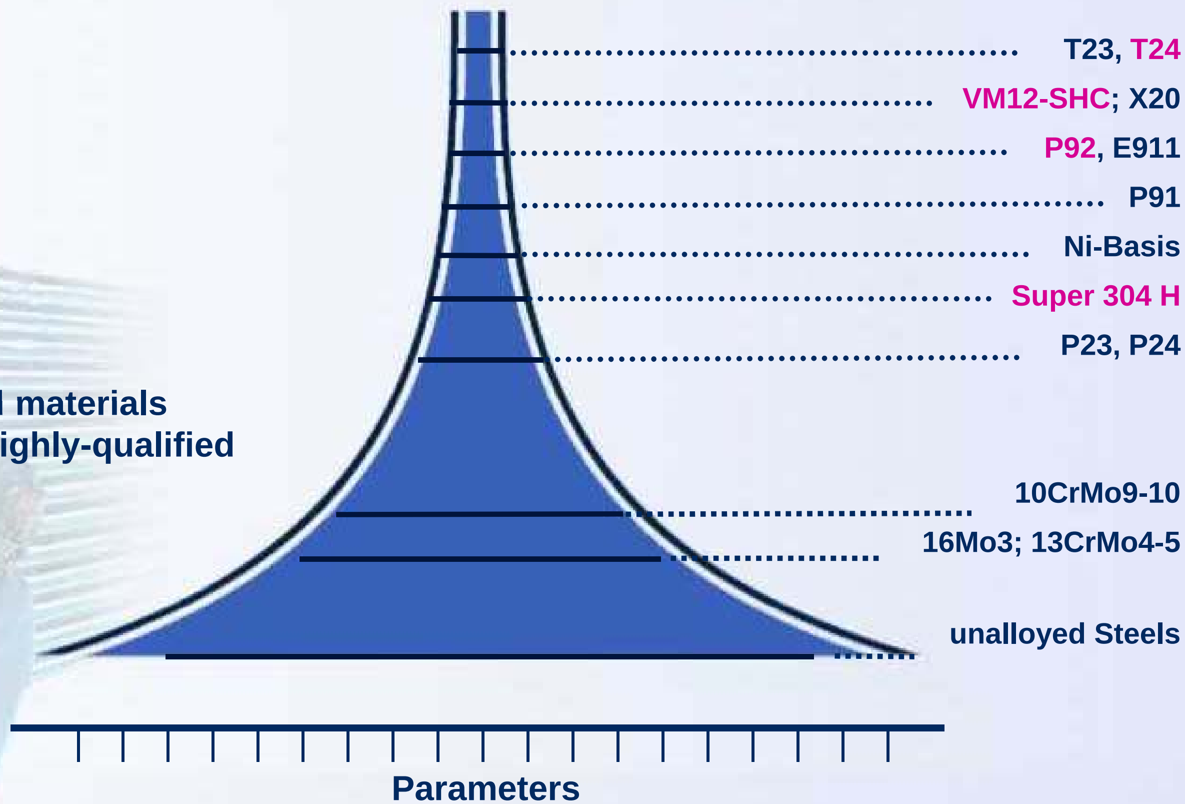
Adherence of these rules enables under field conditions the collecting of weldments for PWH-treatment without time climate.

Power Plant

Main influence:

- Pre heating temperature
- Interpass temperature
- Heat input
- Weld built up
- Thickness of layers
- Bevel preperation
- Geometry of joint
- Weld process
- Welding parameter

The processing of highly-developed materials demands most exact settings and highly-qualified staff.



A good weld metal on it´s own does not guarantee a sound joint , if you do not care for …

Conclusions

- Filler metals for P91 have been developed sometime now . Also developed FM for other martinsitic steels P92 and VM12-SHC is and will be used for the new power plants in Germany, Europe and also in other countries.

- Optimised welding conditions with respect to good mechanical properties, especially CVN – values have been discussed.

- The developed filler metals fulfill the required creep strength at elevated temperature, which can only be guaranteed with conservative long time consuming creep rupture tests.

THANK YOU

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BACK

Böhler Welding GROUP

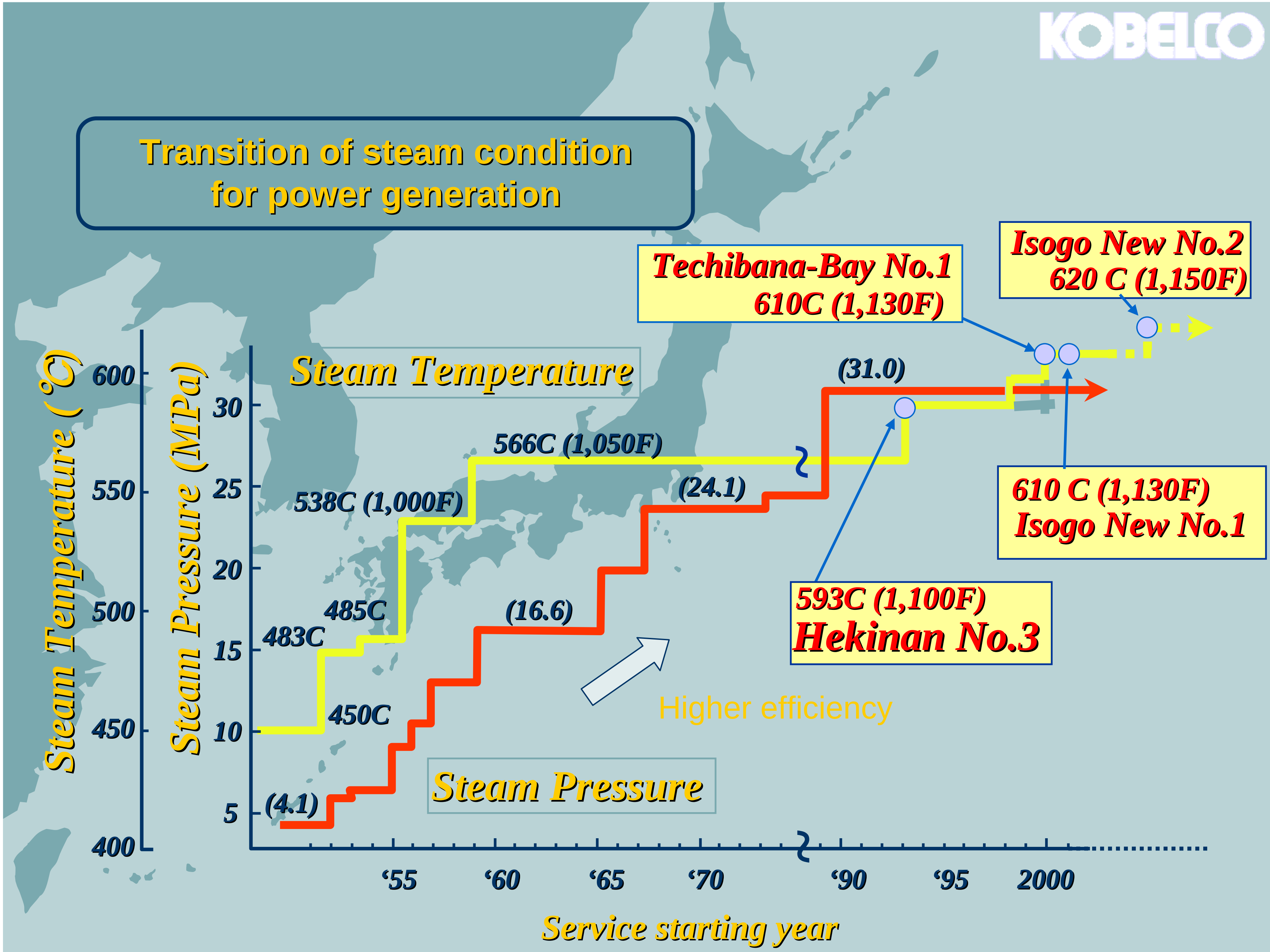
KOBELCO

Welding of P91 materials

KOBE STEEL, LTD.

Welding Business

Technical Development Dept.


KOBELCO
Transition of steam condition
for power generation
Steam Temperature (℃)
Steam Pressure (MPa)
600
550
500
450
400
30
25
20
15
10
5
Steam Temperature
566C (1,050F)
538C (1,000F)
485C
483C
450C
(31.0)
(24.1)
(16.6)
(4.1)
Steam Pressure
Higher efficiency
Techibana-Bay No.1
610C (1,130F)
Isogo New No.2
620 C (1,150F)
610 C (1,130F)
Isogo New No.1
593C (1,100F)
Hekinan No.3
'55
'60
'65
'70
'90
'95
2000
Service starting year

Transition of heat-resistant low-alloy steel for power boilers in conjunction with improvement of creep rupture strength

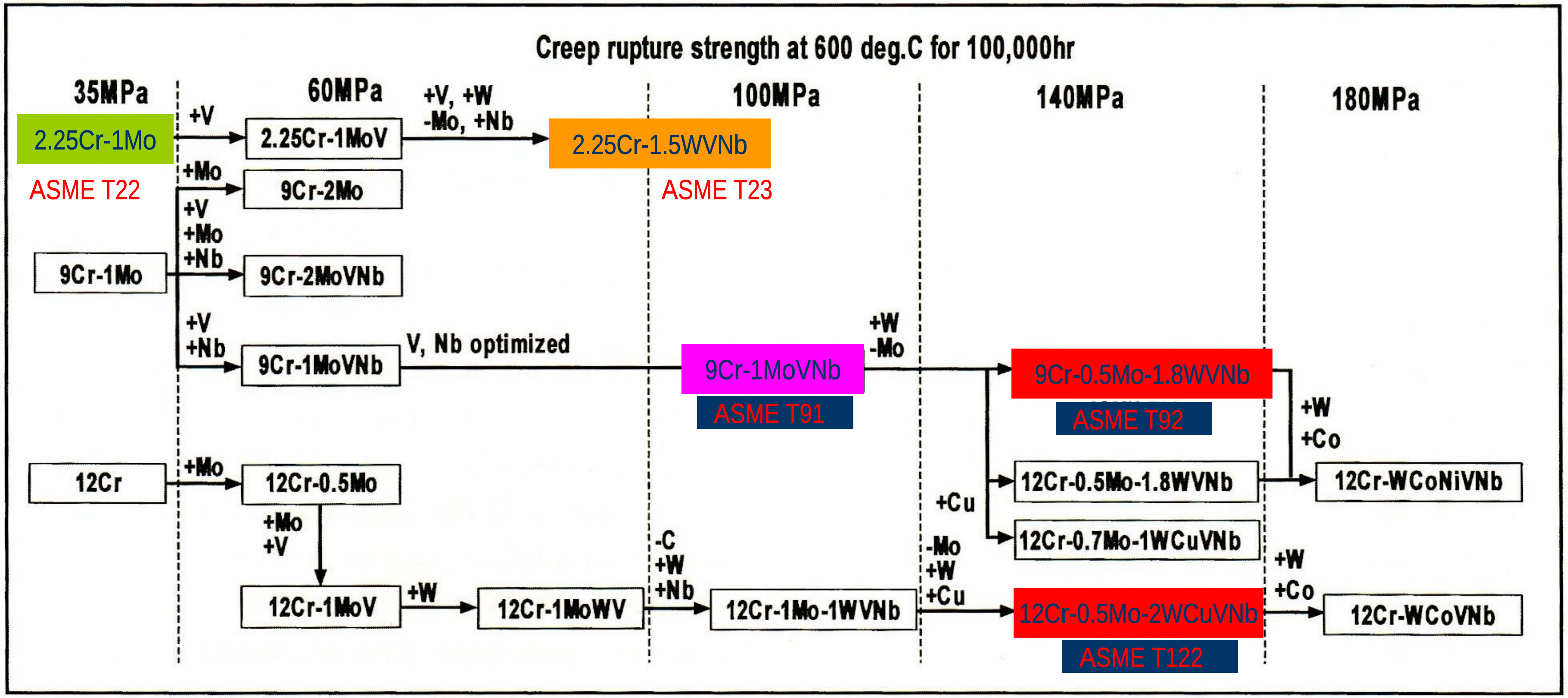
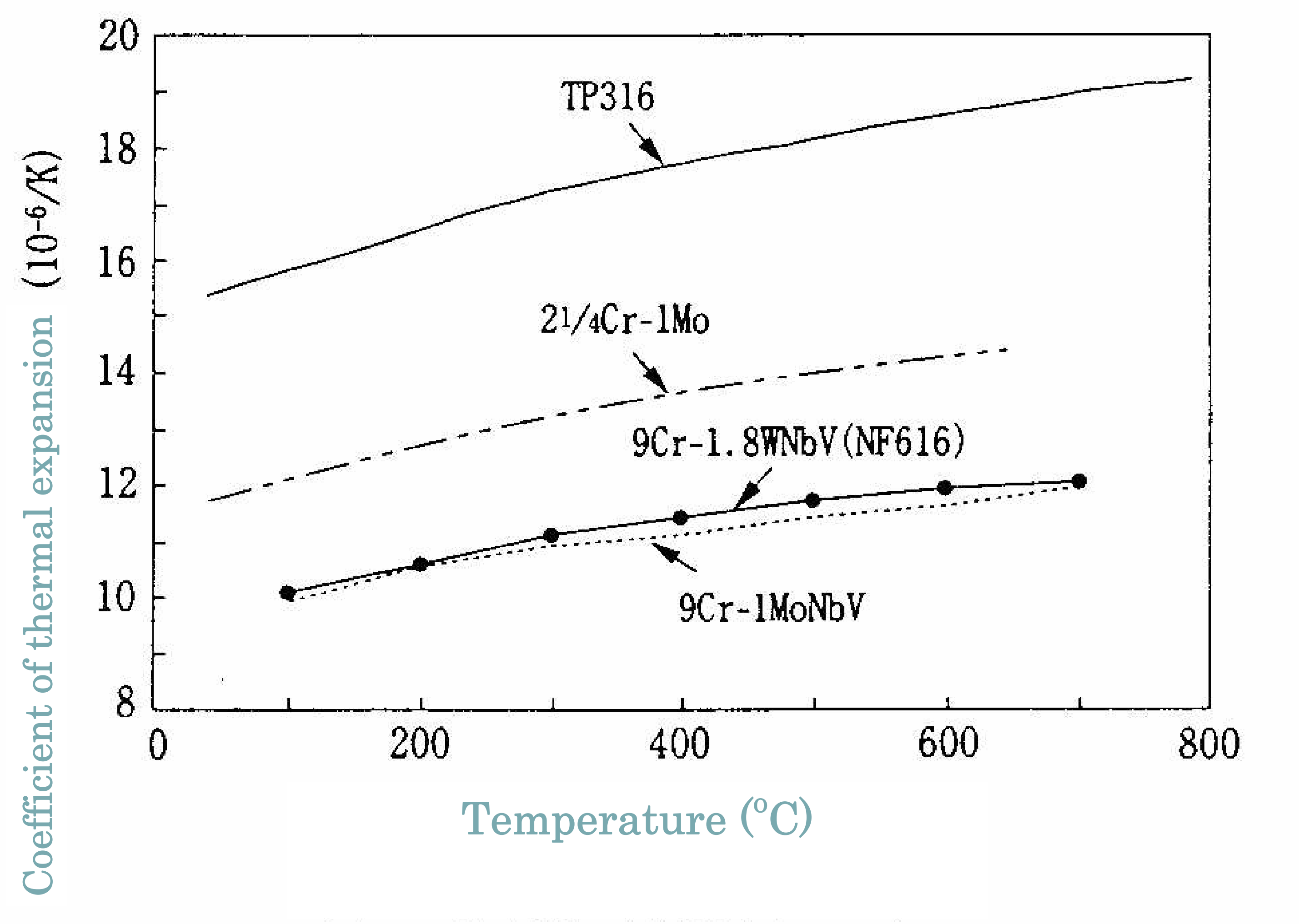


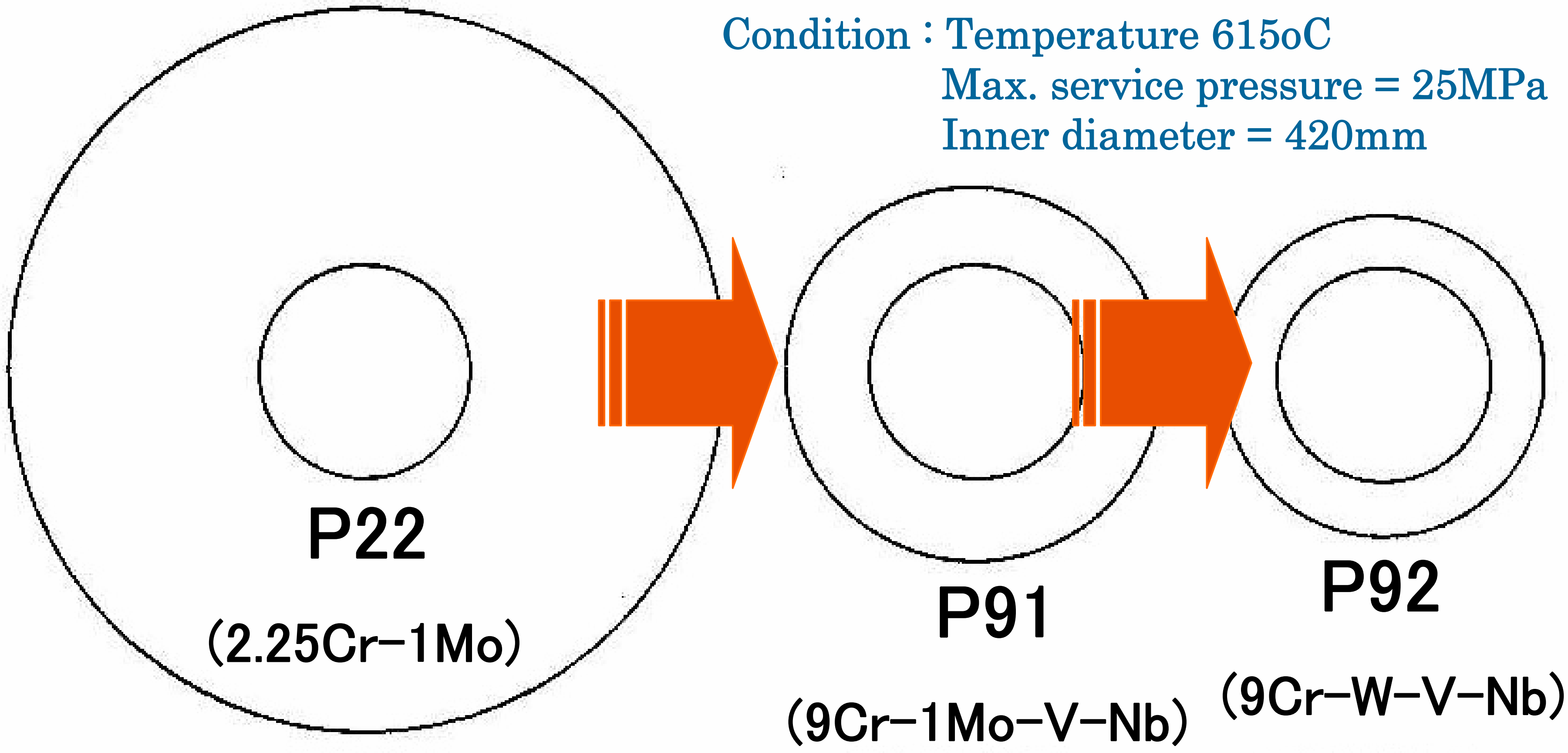
Figure 1. Transition of heat-resistant low-alloy steel for power boilers in conjunction with improvement of creep rupture strength [Ref. 1]

Coefficient of thermal expansion



Development of Steels for Power Generation Boilers

Condition : Temperature 615oC
Max. service pressure = 25MPa
Inner diameter = 420mm



KOBELCO welding consumables for heat resistance low alloy steels

Steel type	SMAW	SAW (Wire/Flux)	GTAW
P/T91	AC/DC: CM-96B9 AC/DC: CM-9Cb	AC: US-90B9/PF-200S DC: US-90B9/PF-90B9 AC/DC: US-9Cb/PF-200S	TG-S90B9 TG-S9Cb
P/T92 P/T122	AC/DC: CR-12S	AC: US-12CRS/PF-200S DC: US-12CRSD/PF-200S(D)	TG-S12CRS

B9 grade for P91 Steel

・Mn+Ni: Max.1.50wt.%

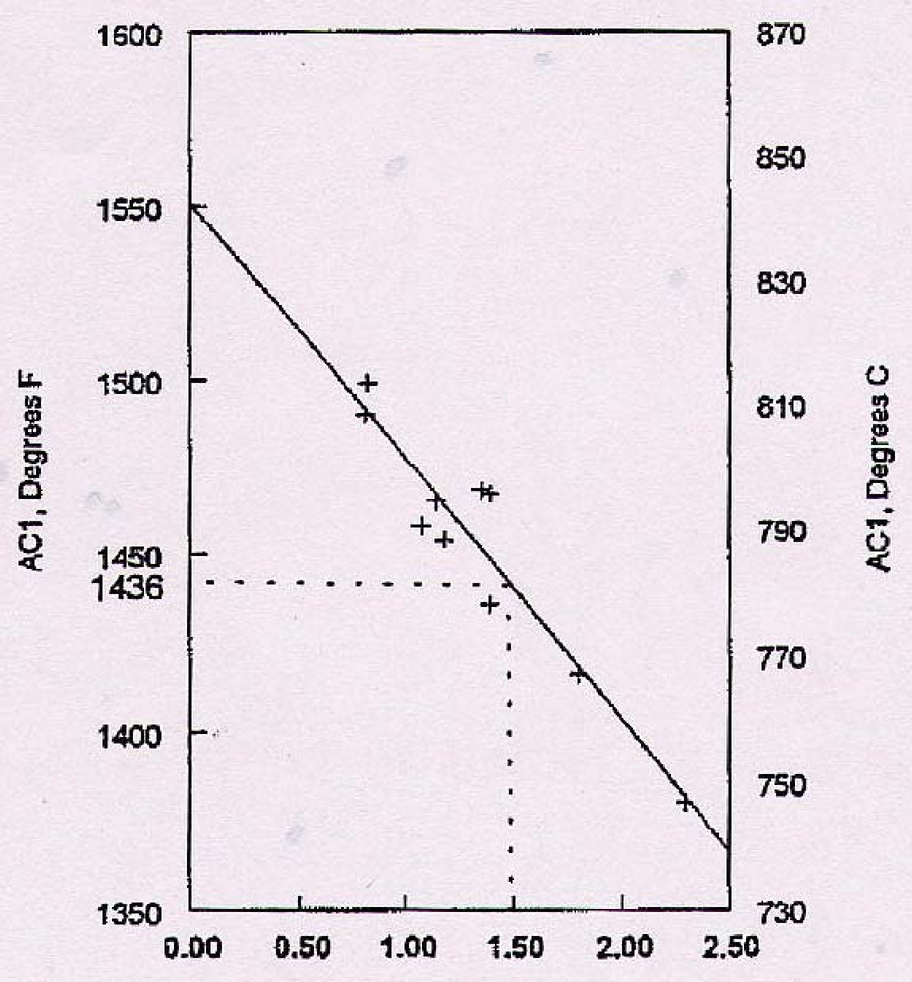
・PWHT: 745±15℃→760±15℃

※ ＜SMAW＞AWS A5.5-2006

＜SAW＞AWS A5.23-2007

＜GTAW, GMAW＞AWS A5.28-2005

B9 standard for P91 Steel



<Background of Revise>

Target: Improvement of Joint properties

↓

Increasing of PWHT Temp.

↓

Increasing A_{c1} Temp. of Weld Metal

↓

Decreasing Mn, Ni of Weld Metal

Mn+Ni of deposited metal wt.% W.F.Newell,Jr.,PE and R.A.Swain

Welding Consumables of B9 grade for ASME Gr.91 Steel

Process	Trade Designation	Chemical Composition of deposited metal (mass%)								
		C	Si	Mn	Ni	Cr	Mo	V	Nb	Mn+Ni
SMAW	CM-96B9	0.10	0.26	0.77	0.45	9.20	1.01	0.20	0.03	1.22
SAW	PF-200S /US-90B9	0.09	0.20	0.82	0.46	8.80	0.92	0.21	0.04	1.28
GTAW	TG-S90B9	0.10	0.24	0.70	0.52	9.11	0.98	0.23	0.05	1.22
AWS規格 B9										Max.1.50

Process	Trade Designation	PWHT Condition	Mechanical Properties of deposited metal			
			0.2%Y.S.	T.S.	vE20℃	C.R.S.※
SMAW	CM-96B9	760℃×4hr	603MPa	743MPa	62J	150MPa
SAW	PF-200S /US-90B9	760℃×4hr	557	692	111	145MPa
GTAW	TG-S90B9	760℃×2hr	706	809	222	155MPa
ASME Gr.91			Min.415	Min.585	---	B.M. 150,W.J. 130

※C.R.S.：600℃×1000hr Creep Rupture Strength

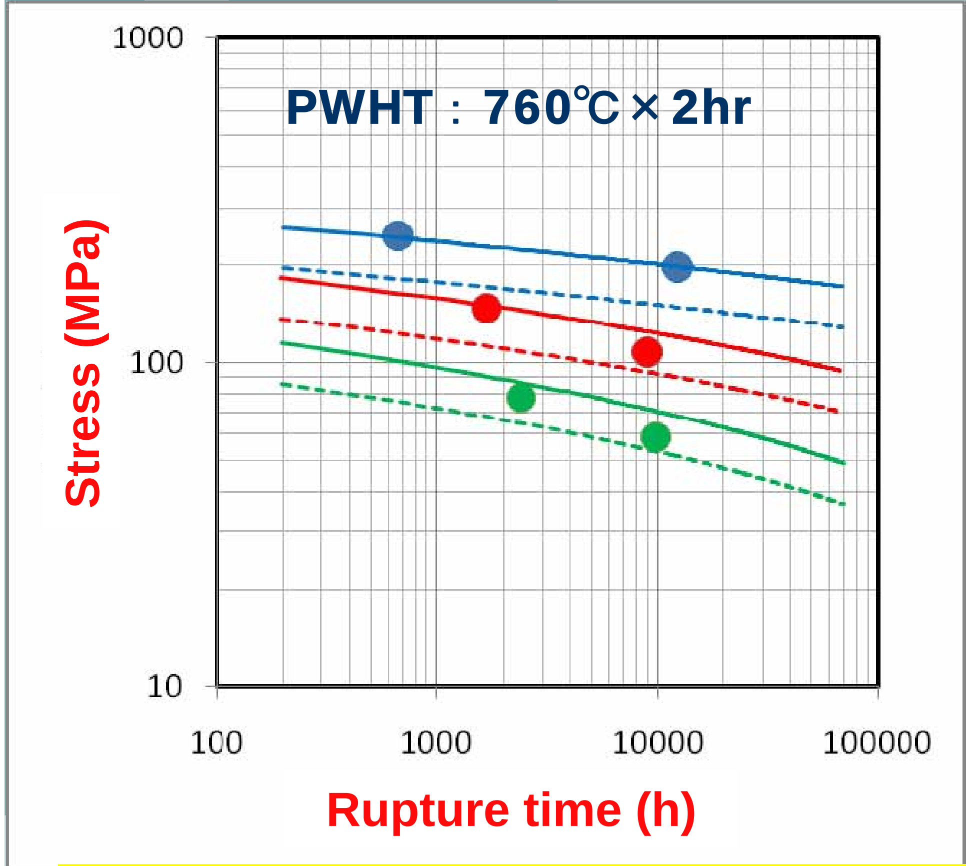
C.R.S. of Gr.91 is estimated from PVP2006-ICPVT11-93350

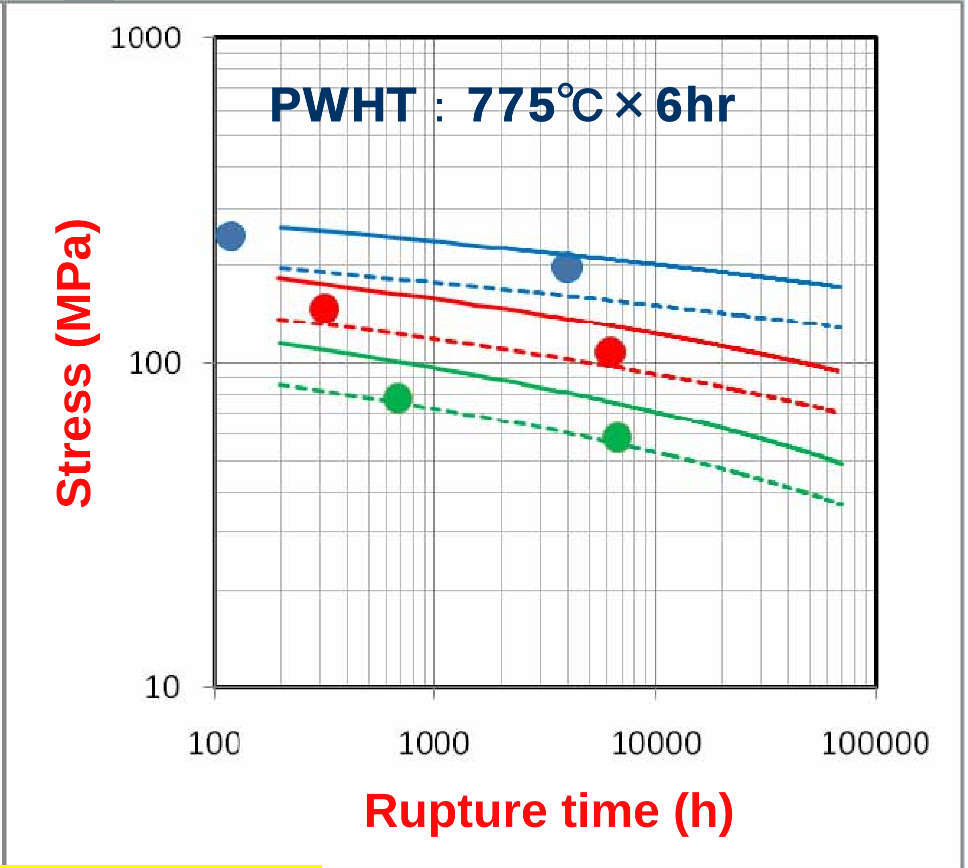
Relationship between
PWHT condition and creep rupture properties of CM-96B9 deposited metal

Solid line：Creep rupture strength forT91/P91Base Metal （NIMS CREEP DATA SHEET No.D-1）

Dotted line：Predicted creep rupture strength for Welding Joints （T91/P91×75%）

●:550℃ ●:600℃ ●650℃ : Creep rupture test result of deposited metal





Max. PWHT Temperature of -B9 : 780℃
Max. PHWT Temperature of -9Cb: 760℃

Welding Consumables for ASME Gr.91 Steel

Process	Trade Designation	Chemical Composition of deposited metal (mass%)								
		C	Si	Mn	Ni	Cr	Mo	V	Nb	Mn+Ni
SMAW	CM-9Cb	0.06	0.31	1.51	0.94	9.11	1.06	0.18	0.03	2.45
SAW	PF-200S /US-9Cb	0.06	0.12	1.58	0.55	8.31	0.88	0.21	0.03	2.13
GTAW	TG-S9Cb	0.07	0.16	0.99	0.68	8.97	0.90	0.18	0.04	1.67
GMAW	MG-S9Cb	0.08	0.27	1.29	0.38	8.86	0.98	0.19	0.03	1.67

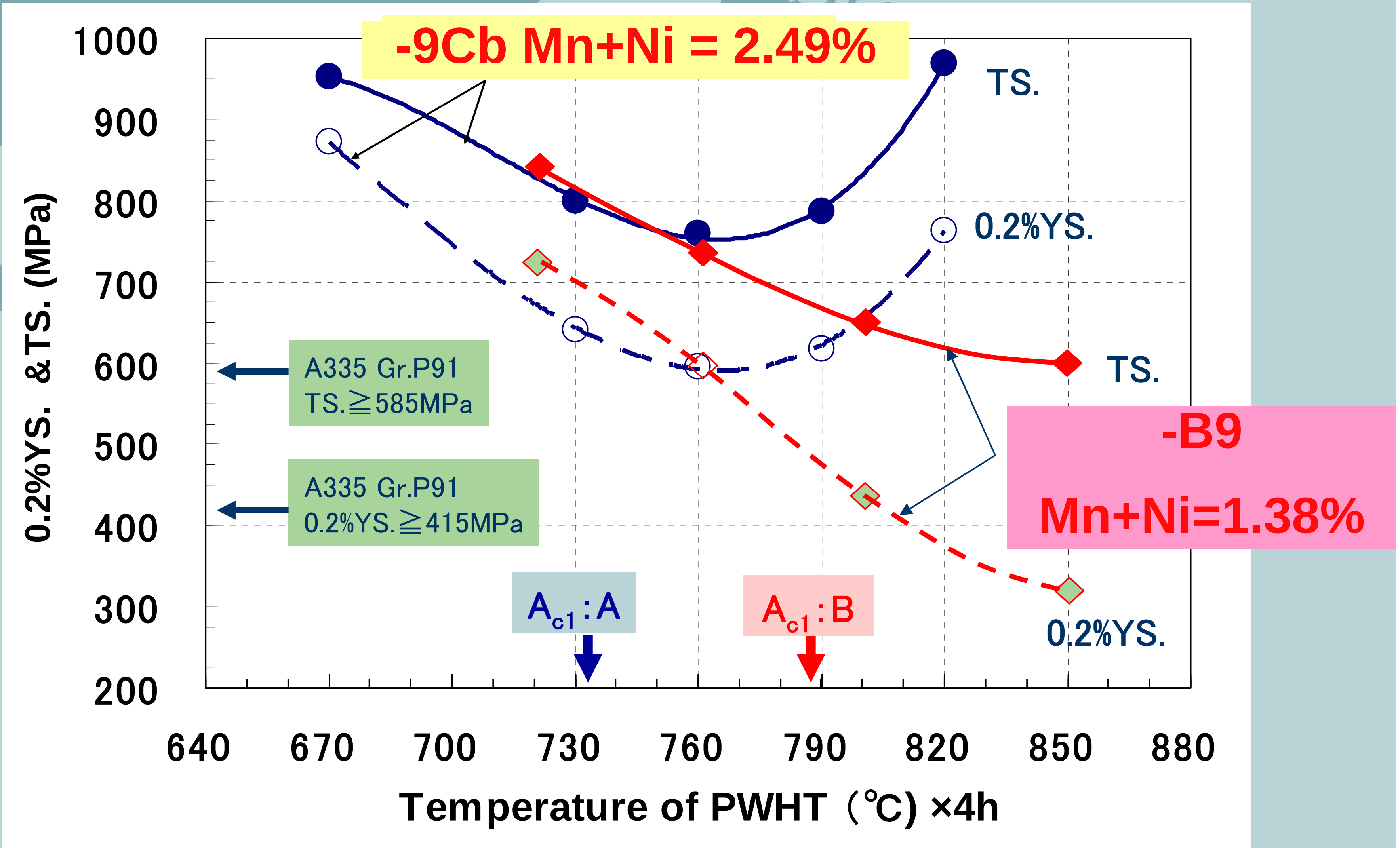
Process	Trade Designation	PWHT Condition	Mechanical Properties of deposited metal			
			0.2%Y.S	T.S.	vE20℃	C.R.S.※
SMAW	CM-9Cb	750℃×5hr	593MPa	756MPa	129J	140MPa
SAW	PF-200S /US-9Cb	740℃×8hr	584	709	95	140
GTAW	TG-S9Cb	740℃×8hr	701	777	>260	155
GMAW	MG-S9Cb	740℃×8hr	568	698	120	135
ASME Gr.91			Min.415	Min.585	---	B.M.150, W.J. 130

※C.R.S.：600℃×1000hr Creep Rupture Strength

C.R.S. of Gr.91 is estimated from PVP2006-ICPVT11-93350

Difference between –B9 and -9Cb

- PWHT temperature vs. TS & YS -



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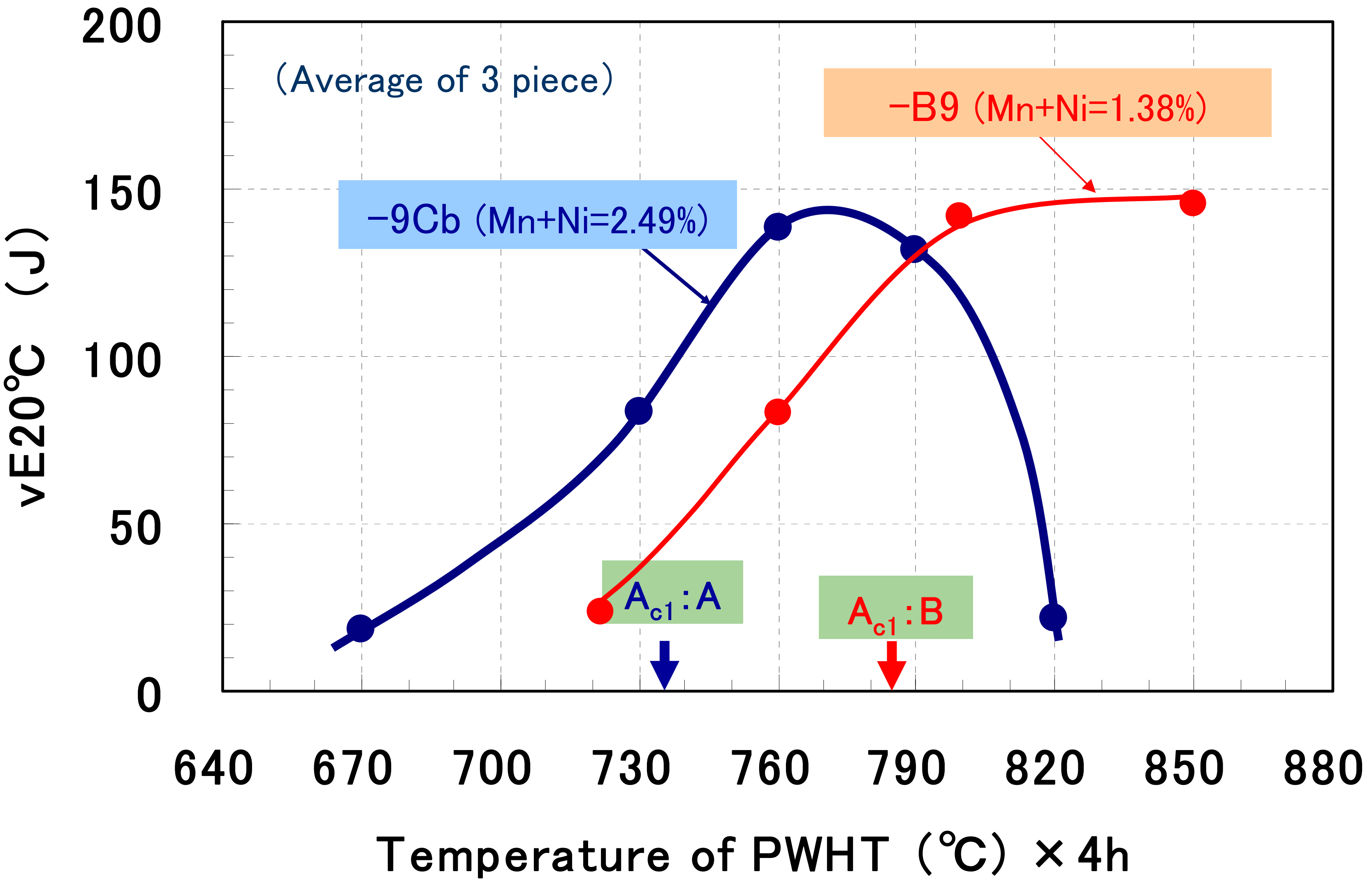
Difference between –B9 and -9Cb

- PWHT temperature vs. IV-



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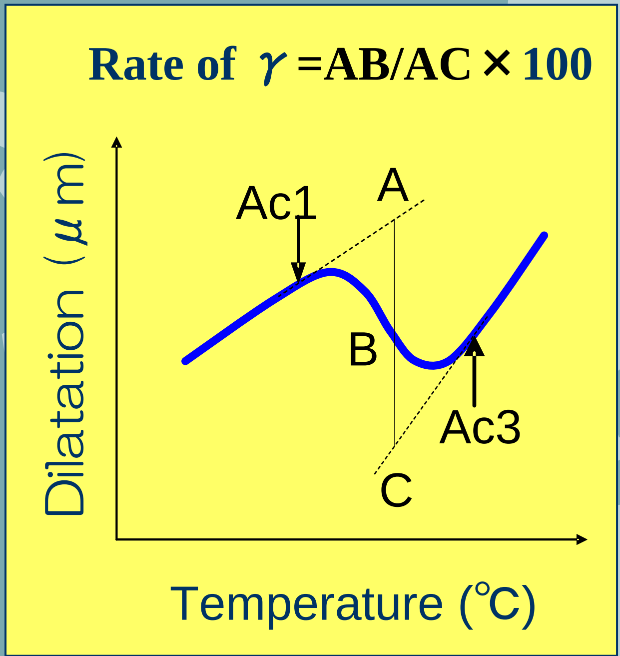
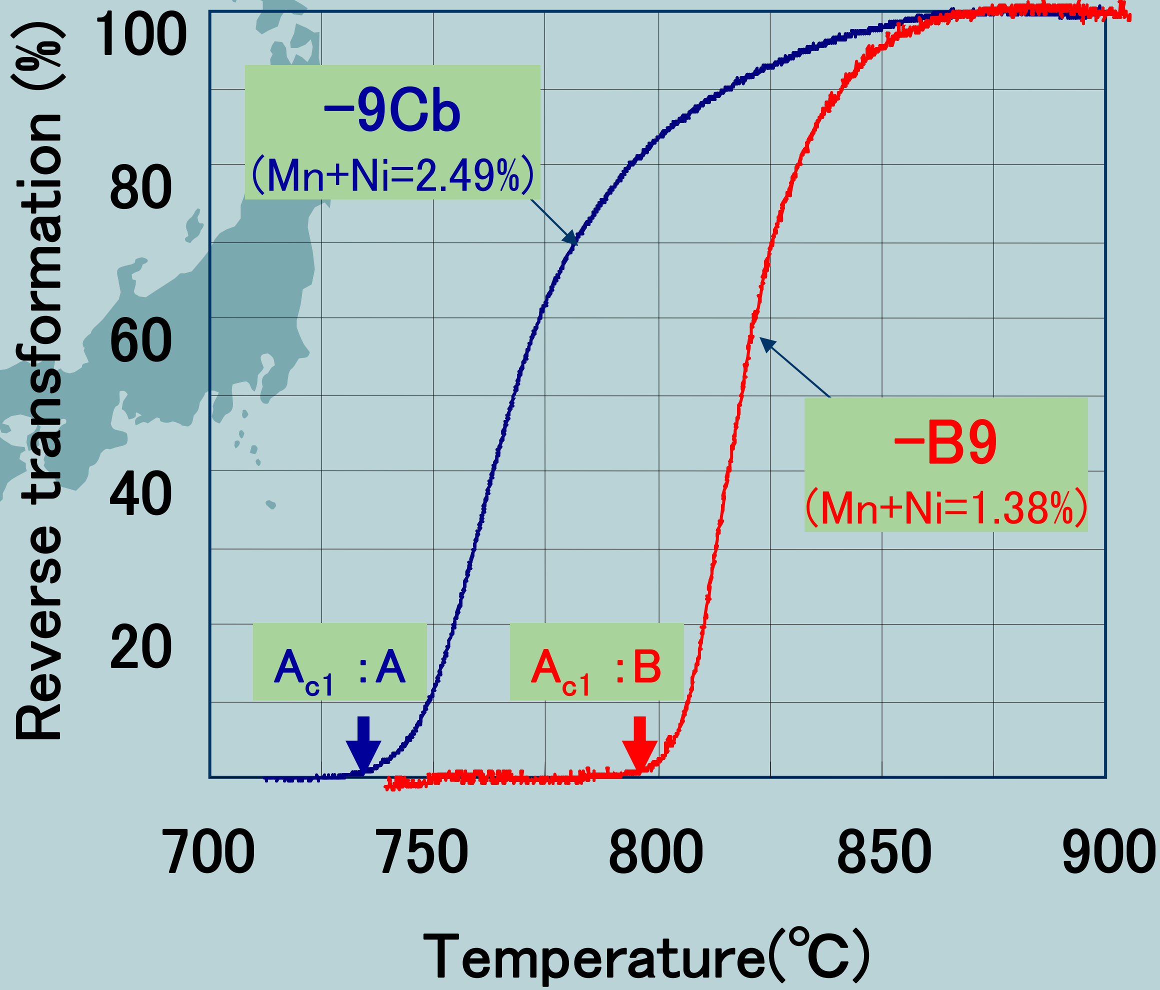
Difference between –B9 and -9Cb

- PWHT temperature vs. transformation rate -



Transformation rate while heating (α→γ)



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Difference between –B9 and -9Cb

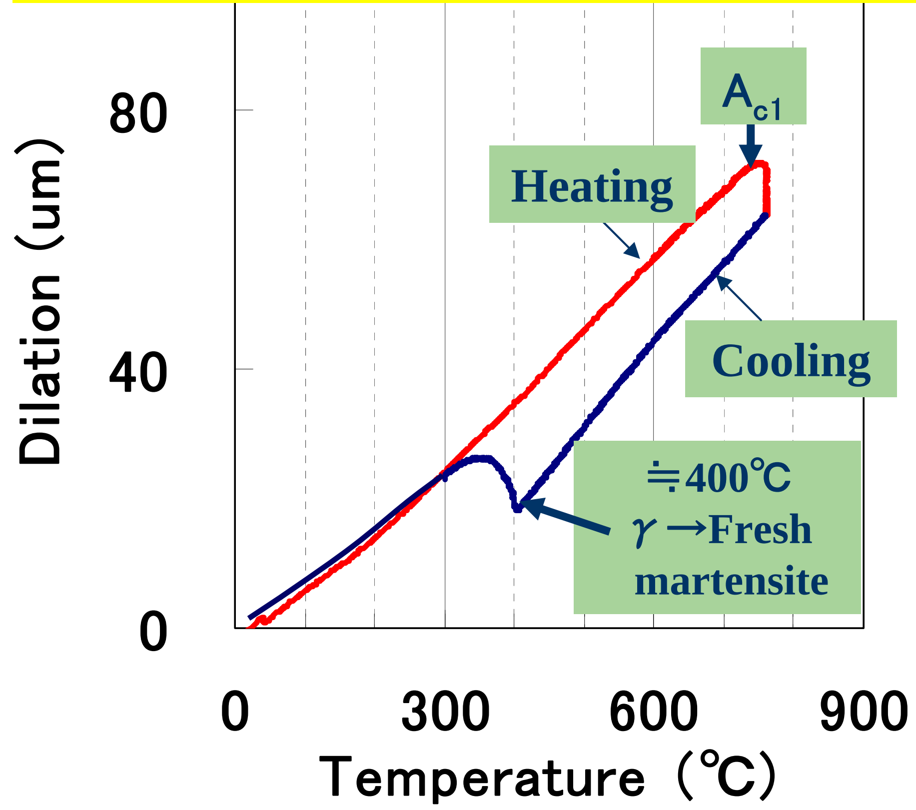
- -B9 vs. -9Cb on temperature-dilation curves -

Changes of dilation during cooling process should be paid attention

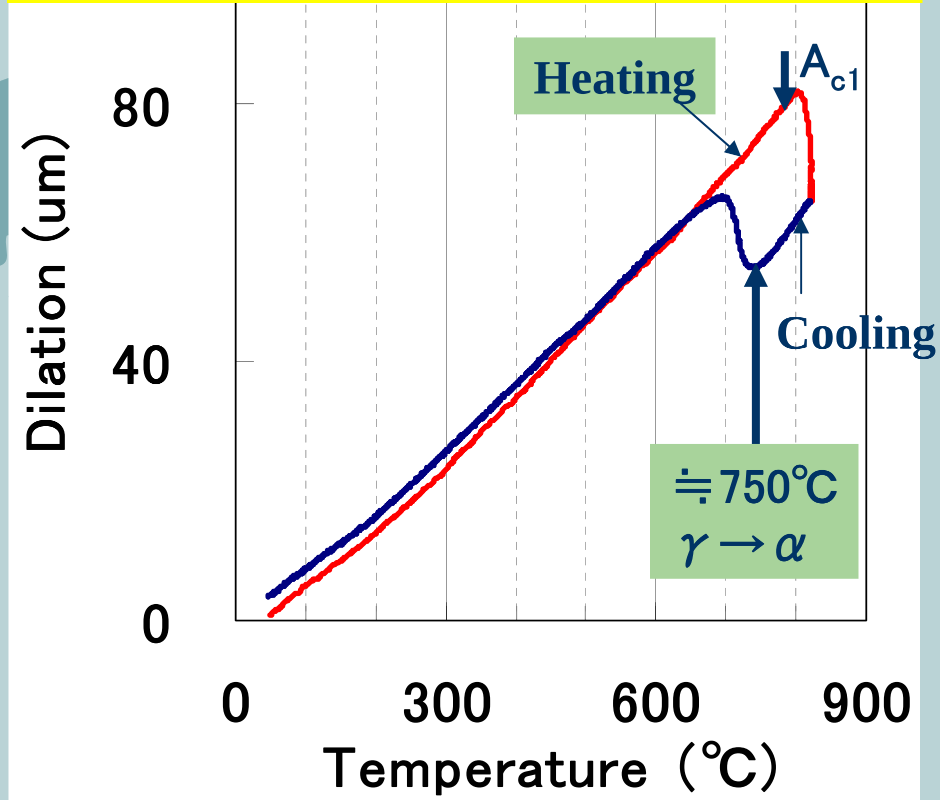
（Cooling rate： 2℃/min、Holding time at the top temperature : 1h）

-9Cb（Mn+Ni=2.49%） **-B9（Mn+Ni=1.38%）**

Top temperature：760℃（A_{c1}+30℃）



Top temperature：820℃（A_{c1}+30℃）



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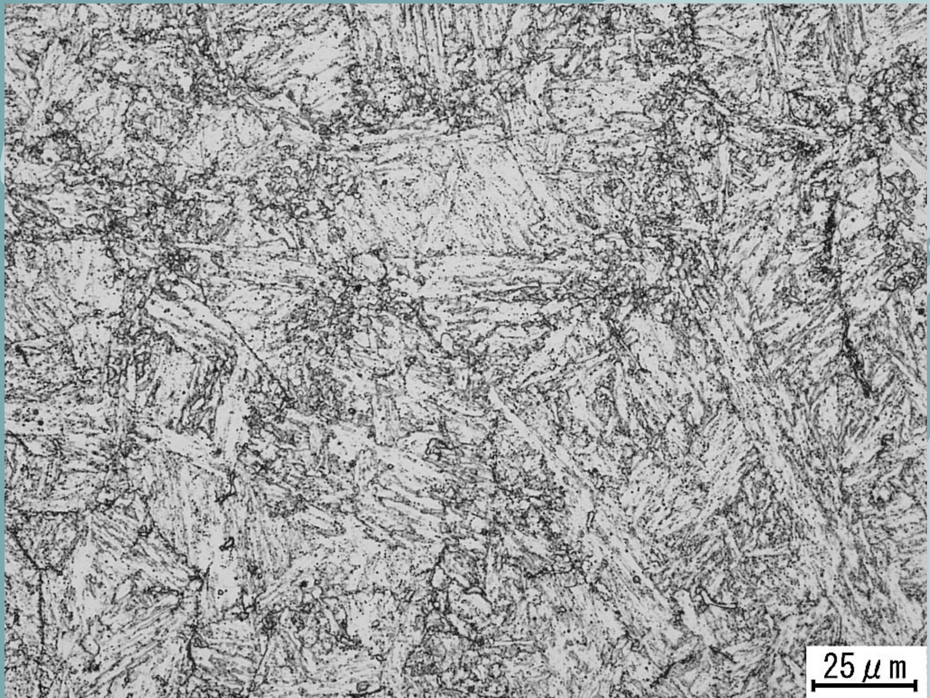
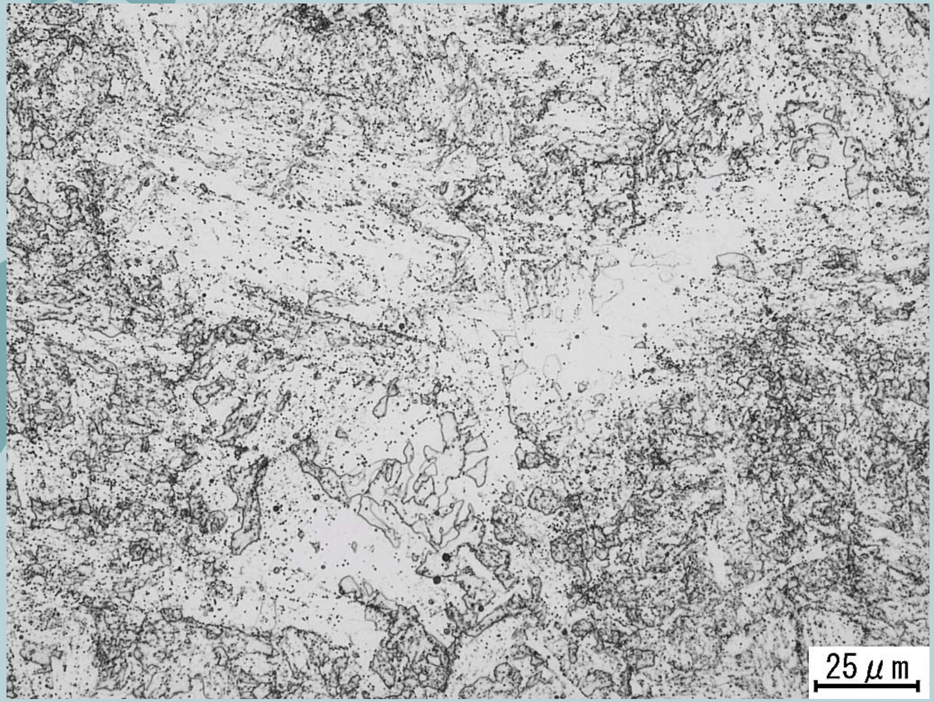
Difference between –B9 and -9Cb

- -B9 vs. -9Cb on microstructure -

-9Cb（Mn+Ni：2.49%）	-B9（Mn+Ni：1.38%）
	
PWHT temperature：760℃（A_{c1}+30℃）	**PWHT temperature：820℃（A_{c1}+30℃）**
⇩	⇩
Tempered martensite + Fresh martensite	**Tempered martensite+Ferrite**

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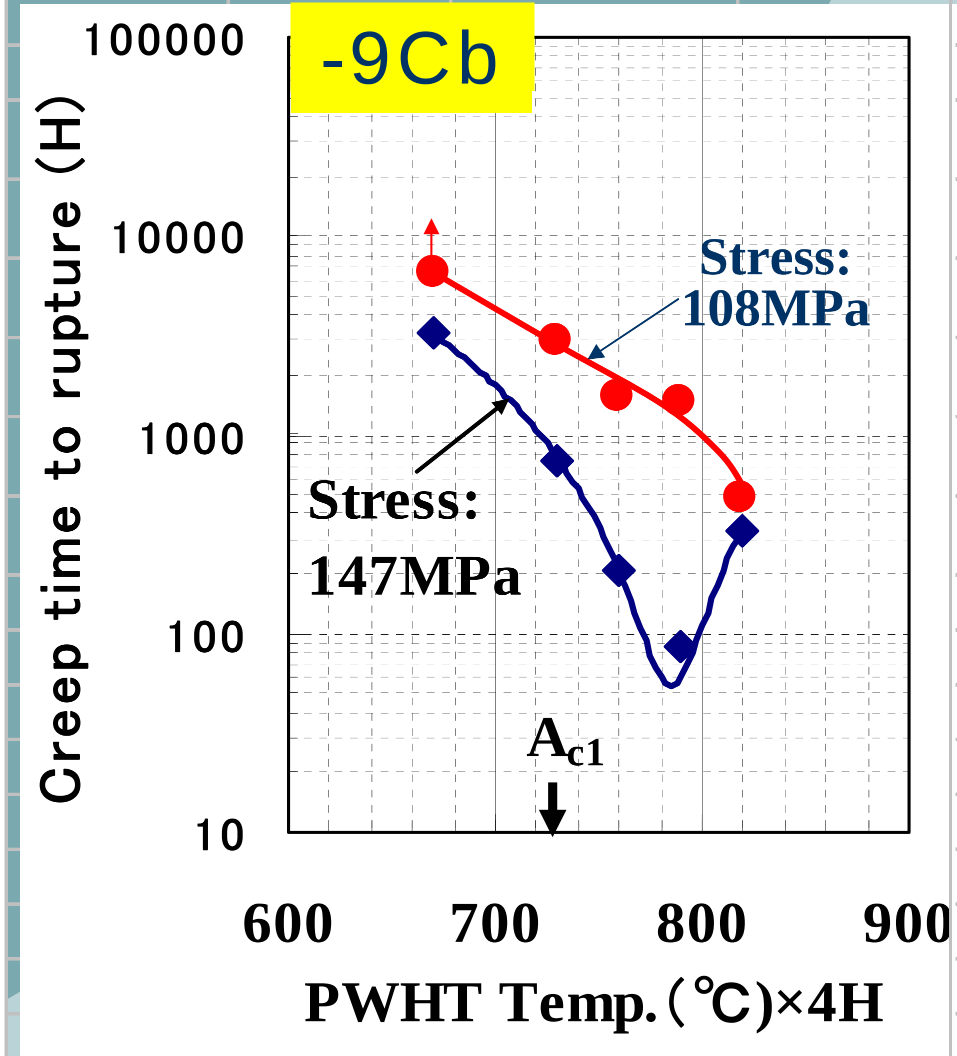
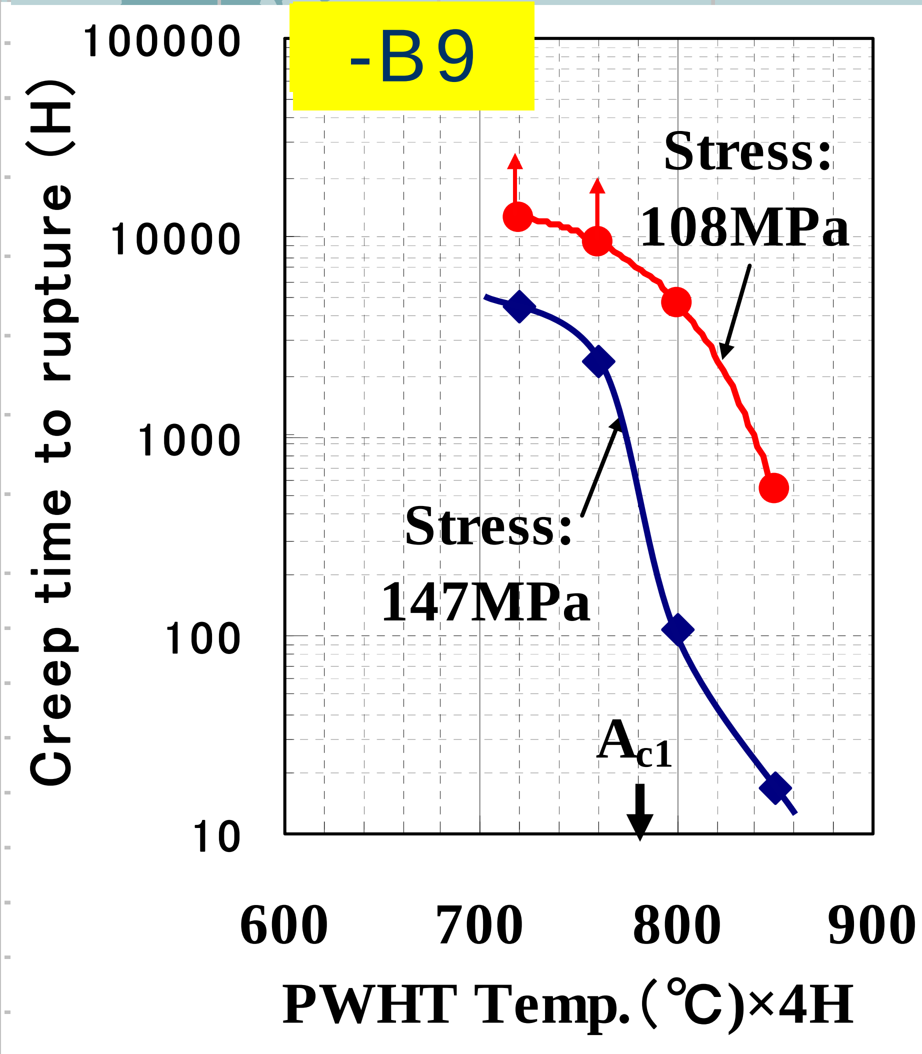
Difference between –B9 and -9Cb

- PWHT temperature vs. Creep rupture strength -





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Examinations of proper PWHT temp.

- **Proper PWHT temperature versus A_{c1}**

A_{c1} of -9Cb : 733℃

A_{c1} of B9 : 785℃

→ **Adequate weld joint properties may not be obtained**

↓

PWHT temp. shouldn't be determined from A_{c1} only

- **Proper PWHT temp. versus mechanical properties**

Particularly,
Creep rupture properties

- **Proper PWHT temp. versus precipitation behaviors**

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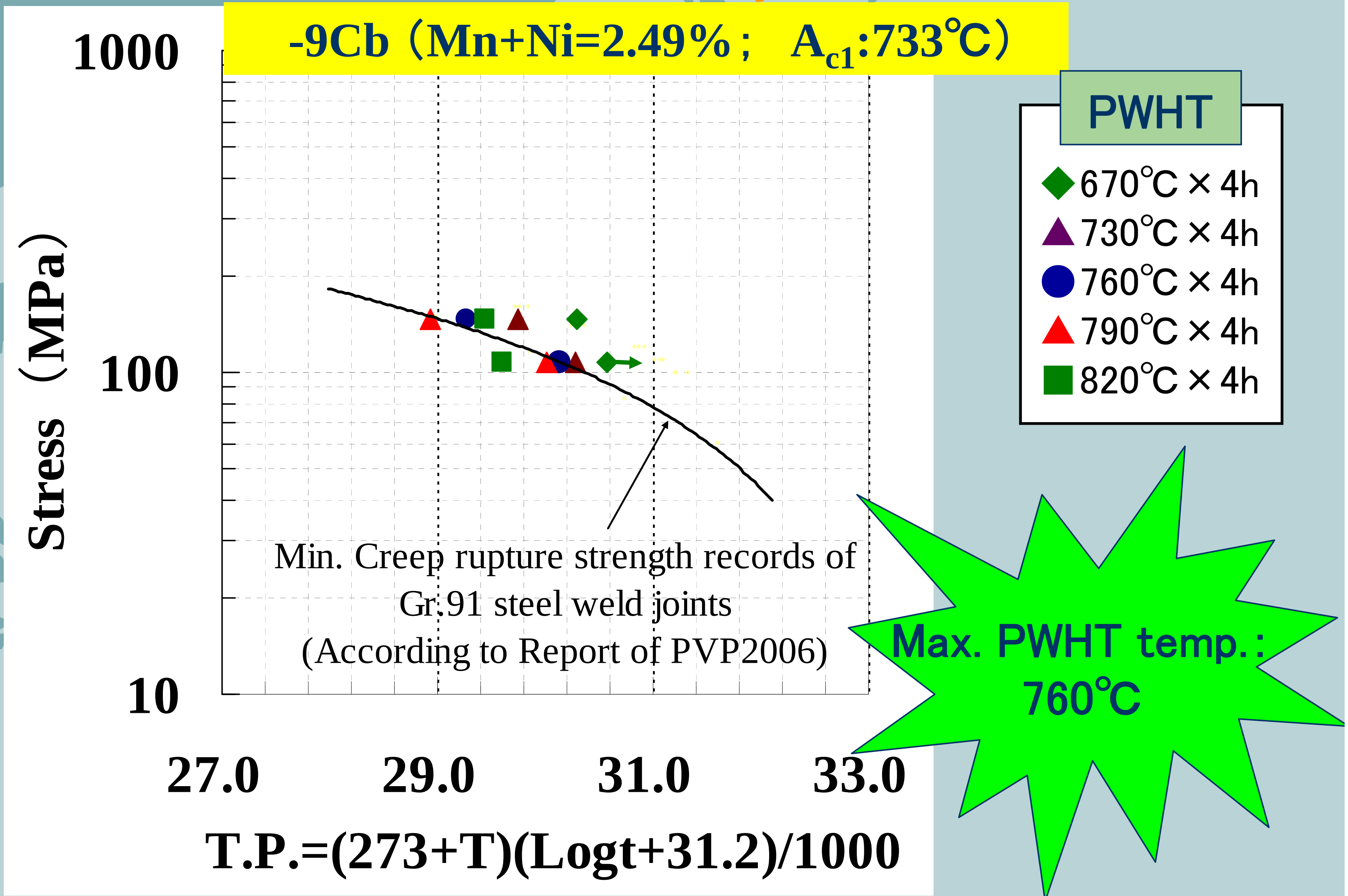
Creep rupture strength of -9Cb vs. Gr.91 weld joints



T:Test temperature (℃)、 t:Time to rupture

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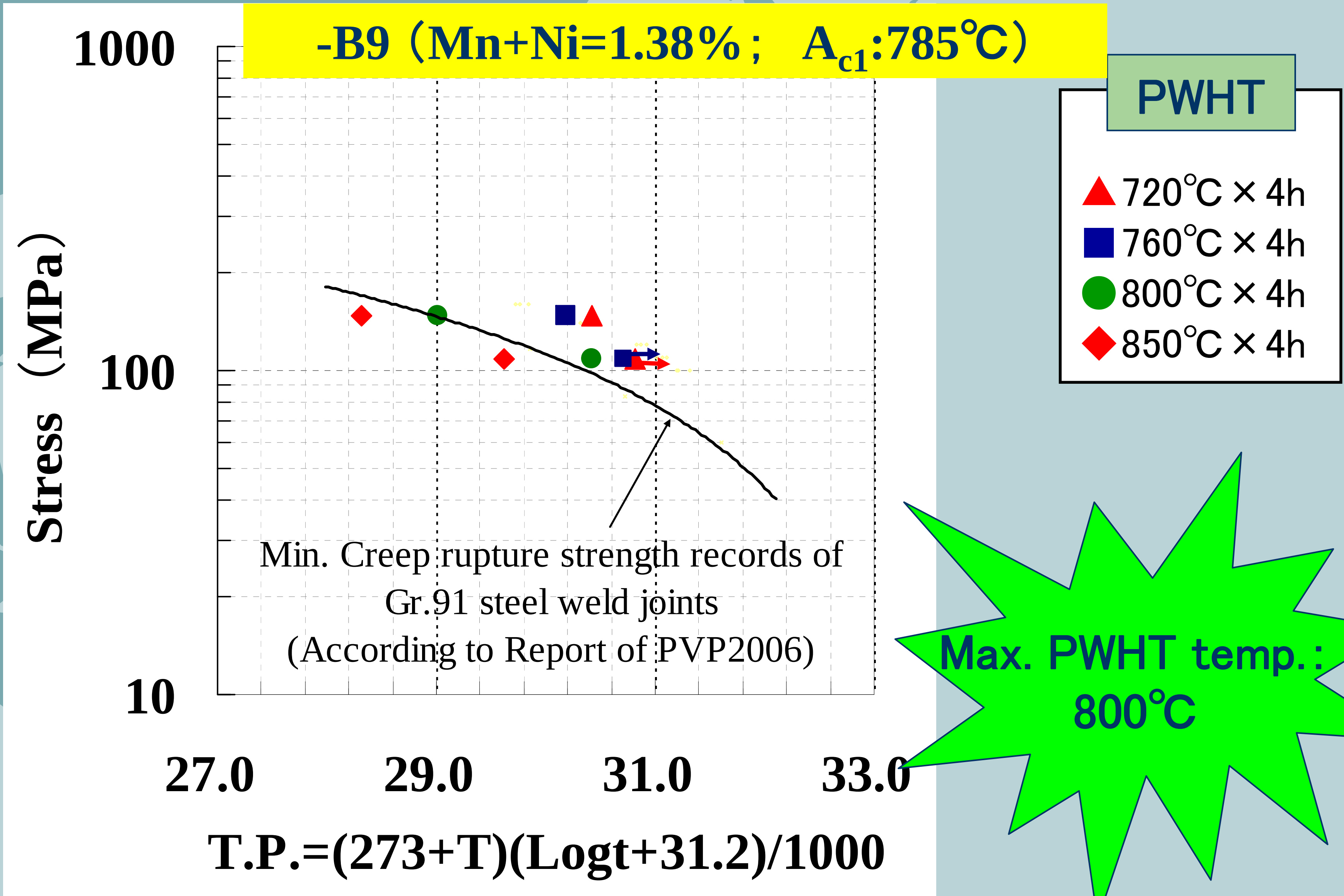
Creep rupture strength of –B9 vs. Gr.91 weld joints



Max. PWHT temp.: 800℃

T:Test temperature (℃)、 t:Time to rupture

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Examinations of proper PWHT temp.

For -9Cb, even PWHT temp. is 760℃ exceeding its A_{c1}

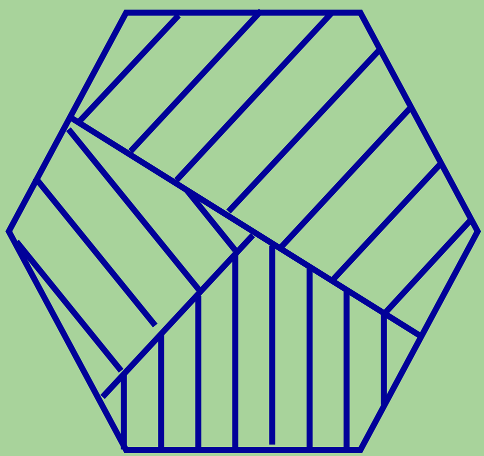
⇩

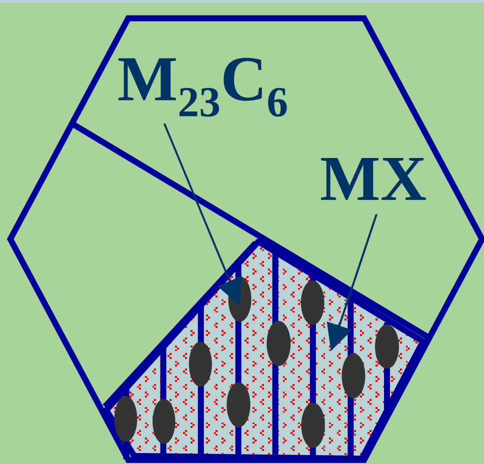
- No steep descent in the creep rupture strength
- Creep rupture strength is equal to or high than the weld joints

⇩

Precipitation should be investigated to confirm PWHT temp.

Microstructure schematic





＜As Weld＞
Fresh martensite

＜After PWHT＞
Tempered martensite

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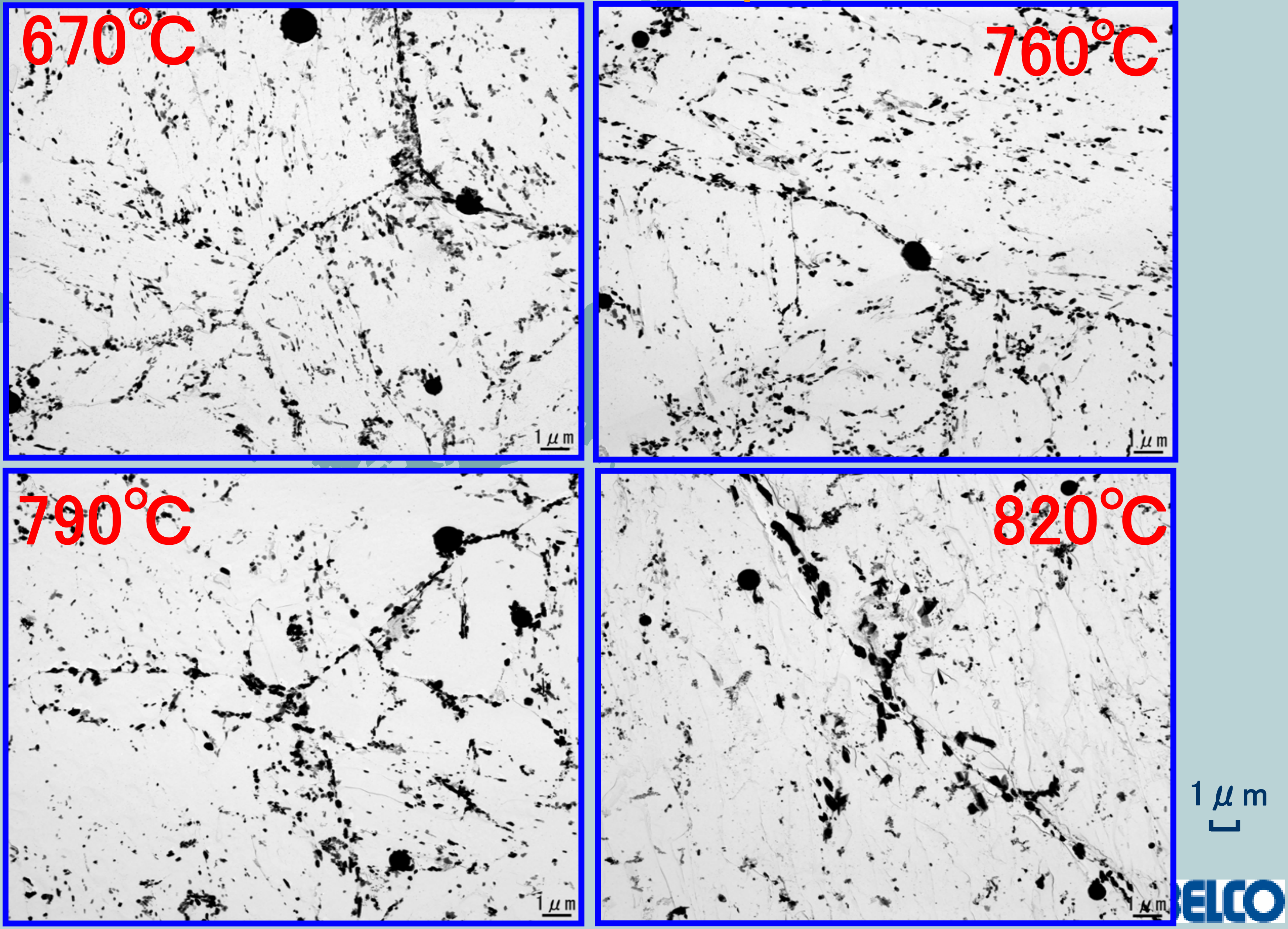
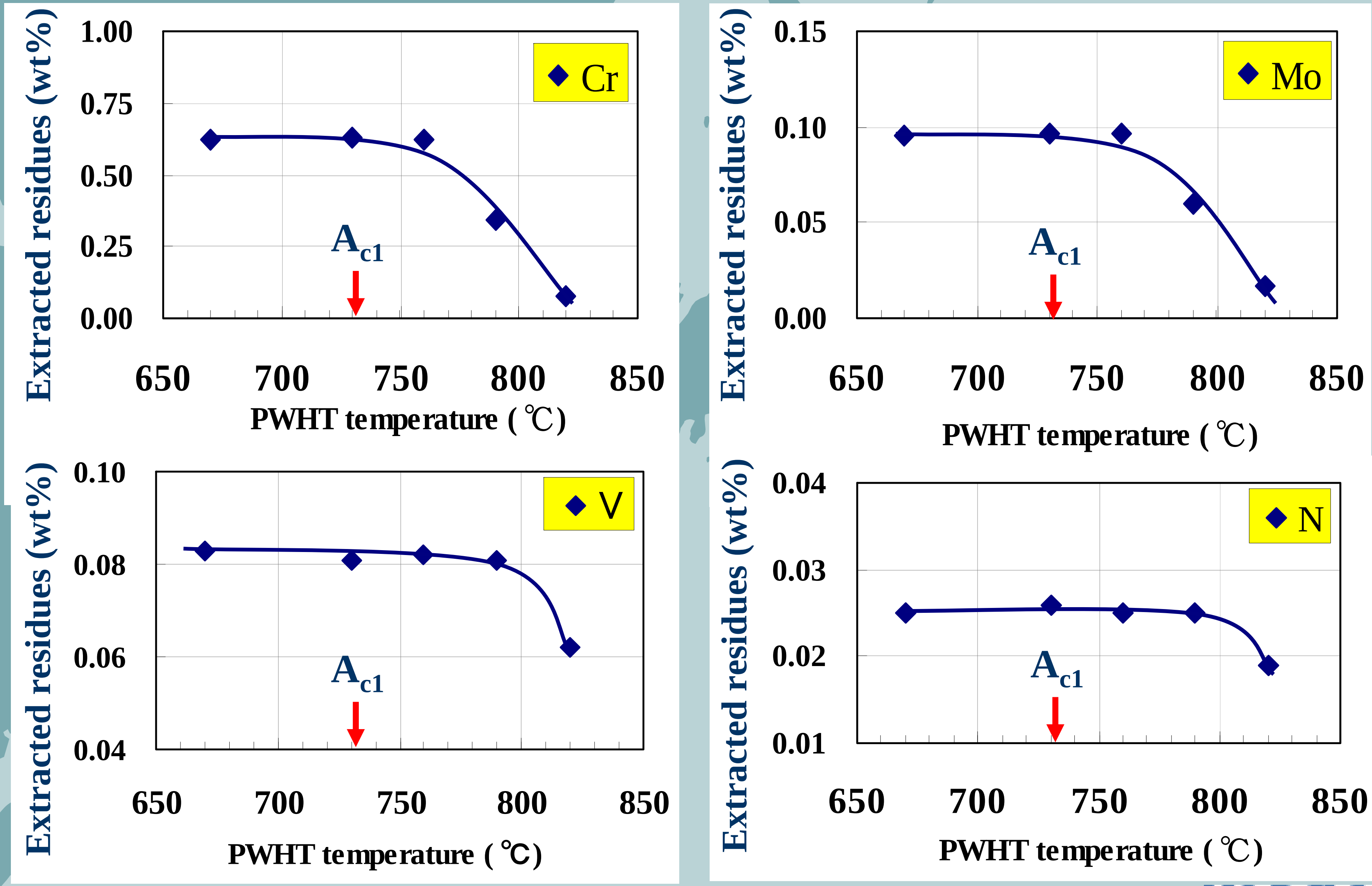
TEM micrographs of -9Cb for individual PWHT temp.



Analysis results of extracted residues of -9Cb



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Tips for Successful Welding of P91 Steel

1. Remedies to cold or delayed cracks

- **Preheating and Inter-pass temp. to 250-350^{o}C**

  Reduction of Cooling Rate for reduction of tensile strength of weld metal.

- **Postweld heating by 250-300oC for 30-60min**

  Conduction before PWHT

  For removing the diffusible hydrogen

- **Re-Drying before use welding consumables**

  For SMAW and SAW flux

  SMAW: 350oC for 1hour

  SAW flux: 250oC for 1hour

Tips for Successful Welding of P91 Steel

2. Preventing hot or solidification cracks

- **Selection of Optimum Welding Condition**

Excessively high welding currents should be avoided

Tips for Successful Welding of P91 Steel

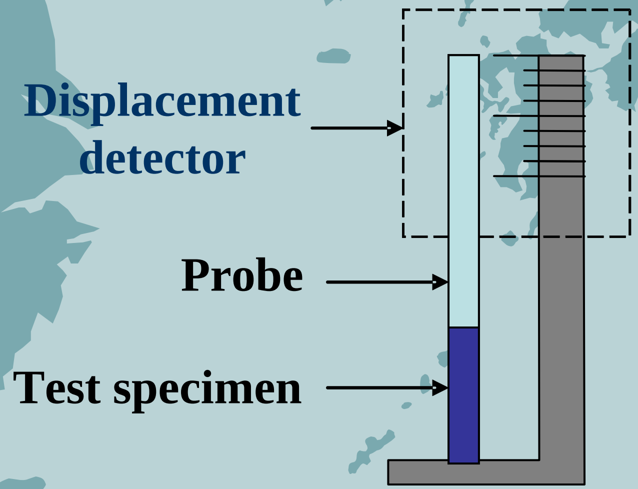
3. Proper PWHT temperature

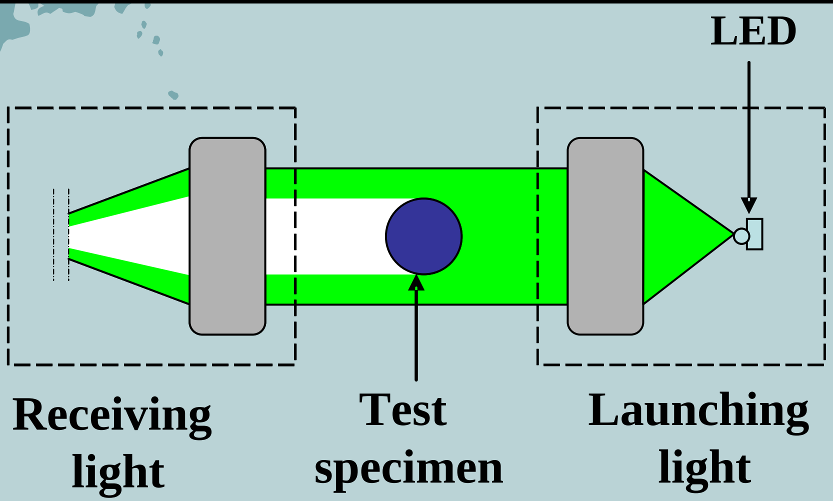
- 710-760oC for -9Cb
- 710-800oC for –B9

Thank you for your attention

Measuring methods and results of A_{c1}

Methods	①	②	③ (DTA)
Measuring quantity	Longitudinal strain	Diametrical strain	Differential temperature
Measuring device	LVDT	LED beam	Thermocouples
Atmosphere	N_2	High-vacuum	Flowing Ar
Heating rate	10℃/s (RT-600℃)、5℃/min (600−1050℃)		





＜Method①: Measurement of longitudinal strain by LVDT＞

＜Method②: Measurement of diametrical strain by LED＞

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Measuring methods and results of A_{c1}

Methods	①	②	③ (DTA)
Measuring quantity	Longitudinal strain	Diametrical strain	Differential temperature
Measuring device	LVDT	LED beam	Thermocouples
Atmosphere	N_2	High-vacuum	Flowing Ar
Heating rate	10℃/s (RT-600℃)、5℃/min (600−1050℃)		
-9Cb (Mn+Ni=2.49%)	696℃	733℃	Couldn't be determined
-B9 (Mn+Ni=1.38%)	758℃	785℃	795℃
Carbon steel	699℃	732℃	731℃
Remarks	Oxide film generated	Oxide film didn't generate on the specimens surface	

KOBELCO

BACK

METRODE
WELDING CONSUMABLES

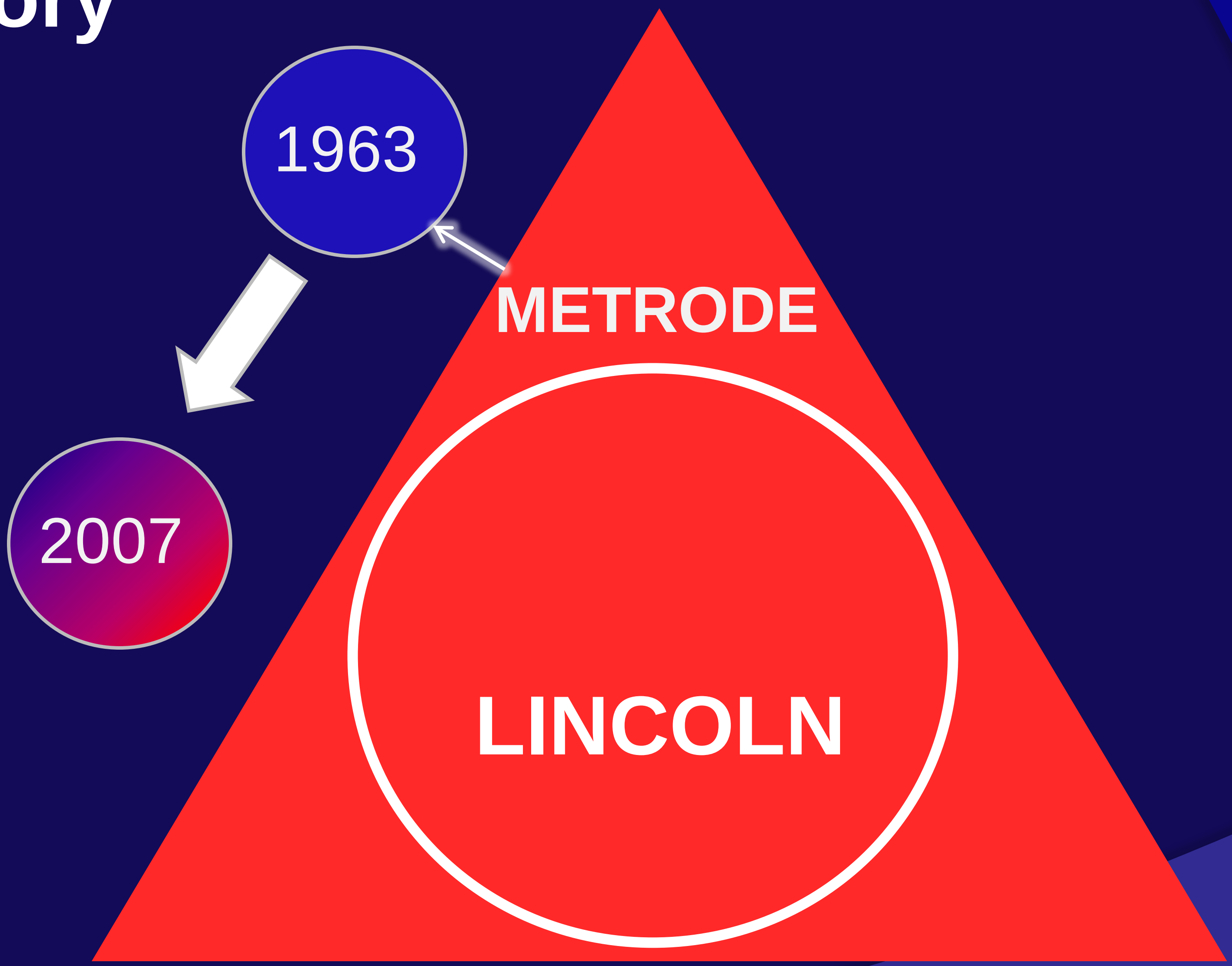
A Lincoln Electric ® Company

Dr. Raghvendra Srivastava

Metrode Products Limited, UK

METRODE
WELDING CONSUMABLES

History



METRODE
WELDING CONSUMABLES

Location

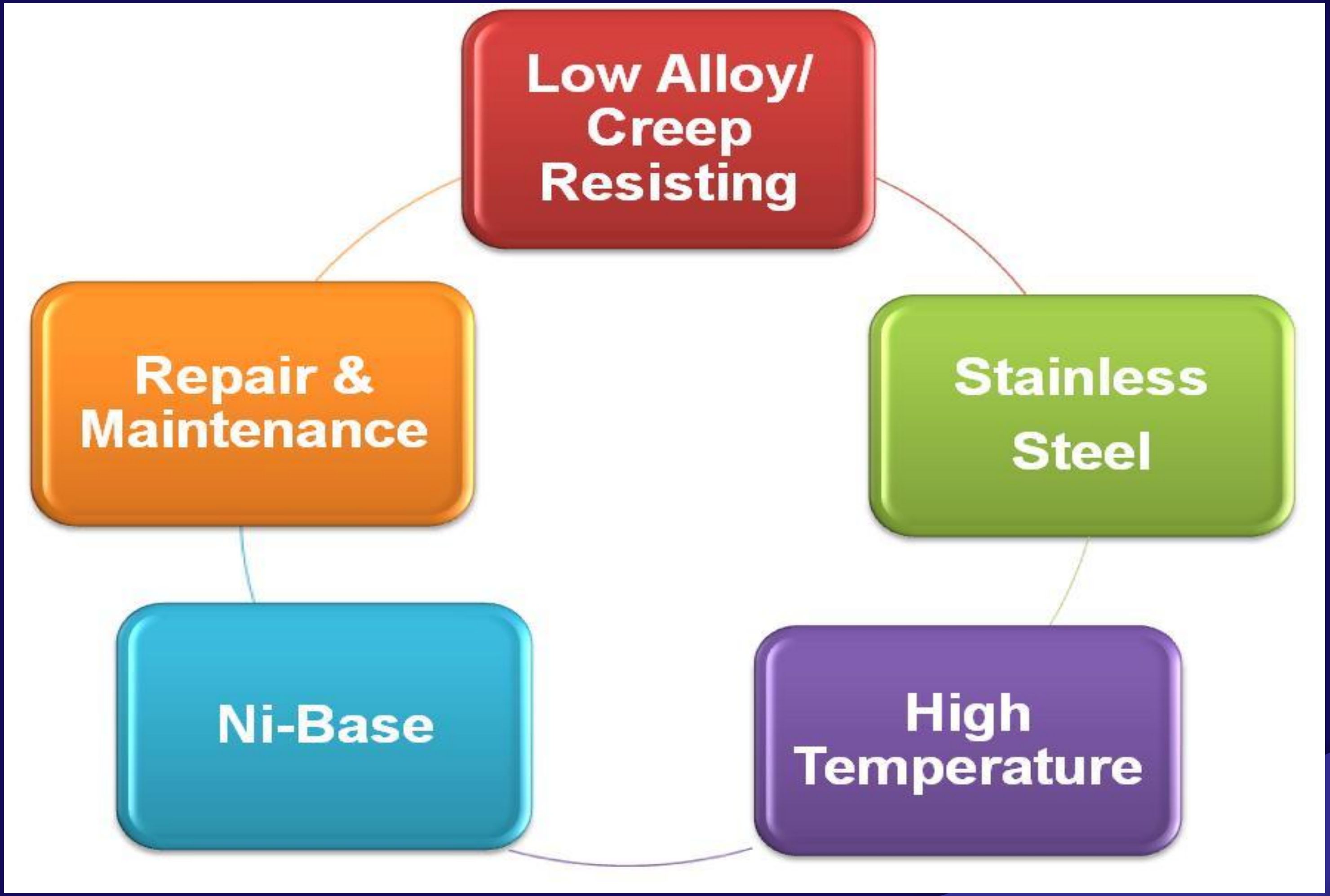
Chertsey, Surrey
UK
Near Heathrow Airport

METRODE
WELDING CONSUMABLES

Products

METRODE
WELDING CONSUMABLES

Product Range

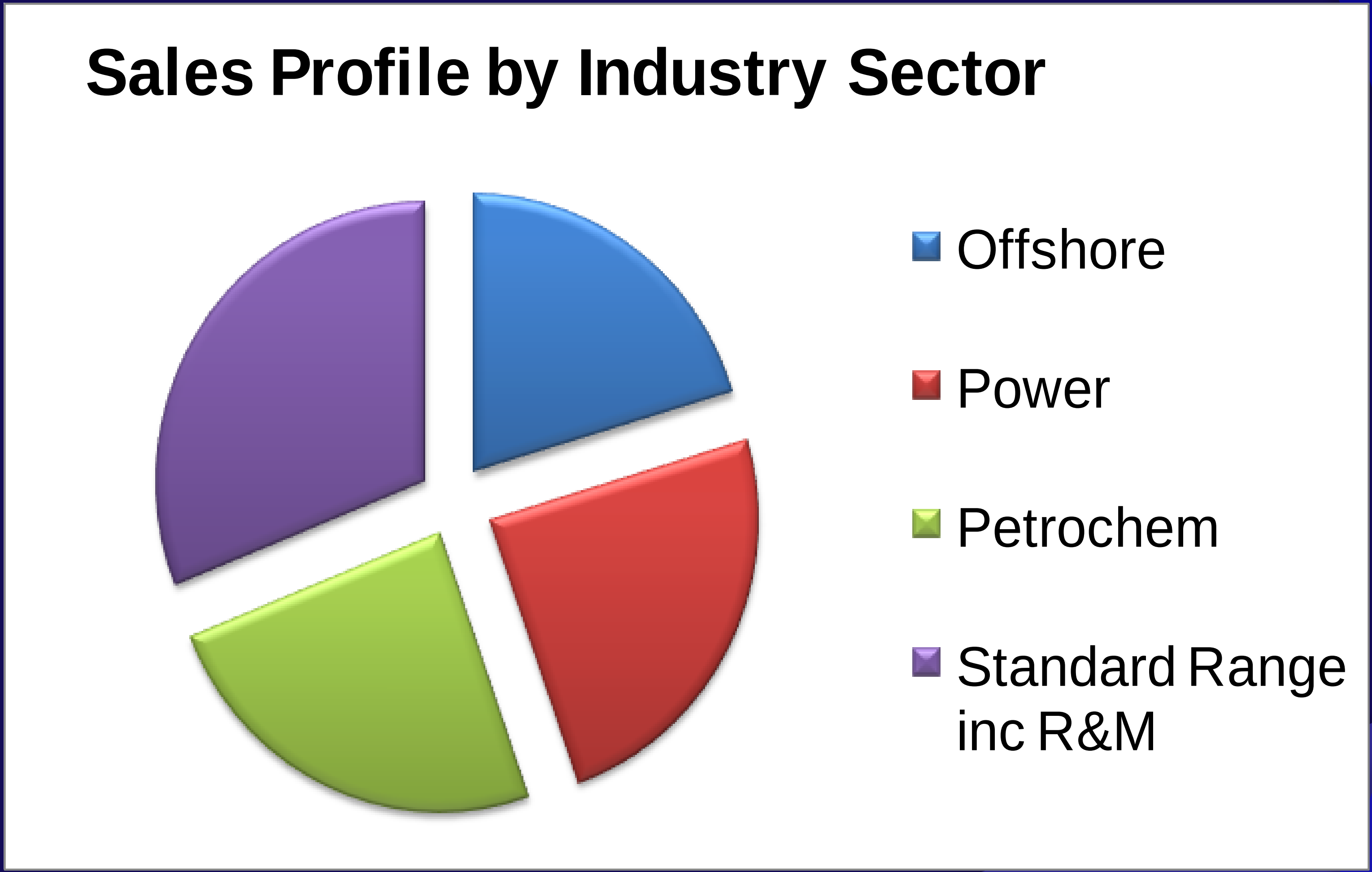


Products

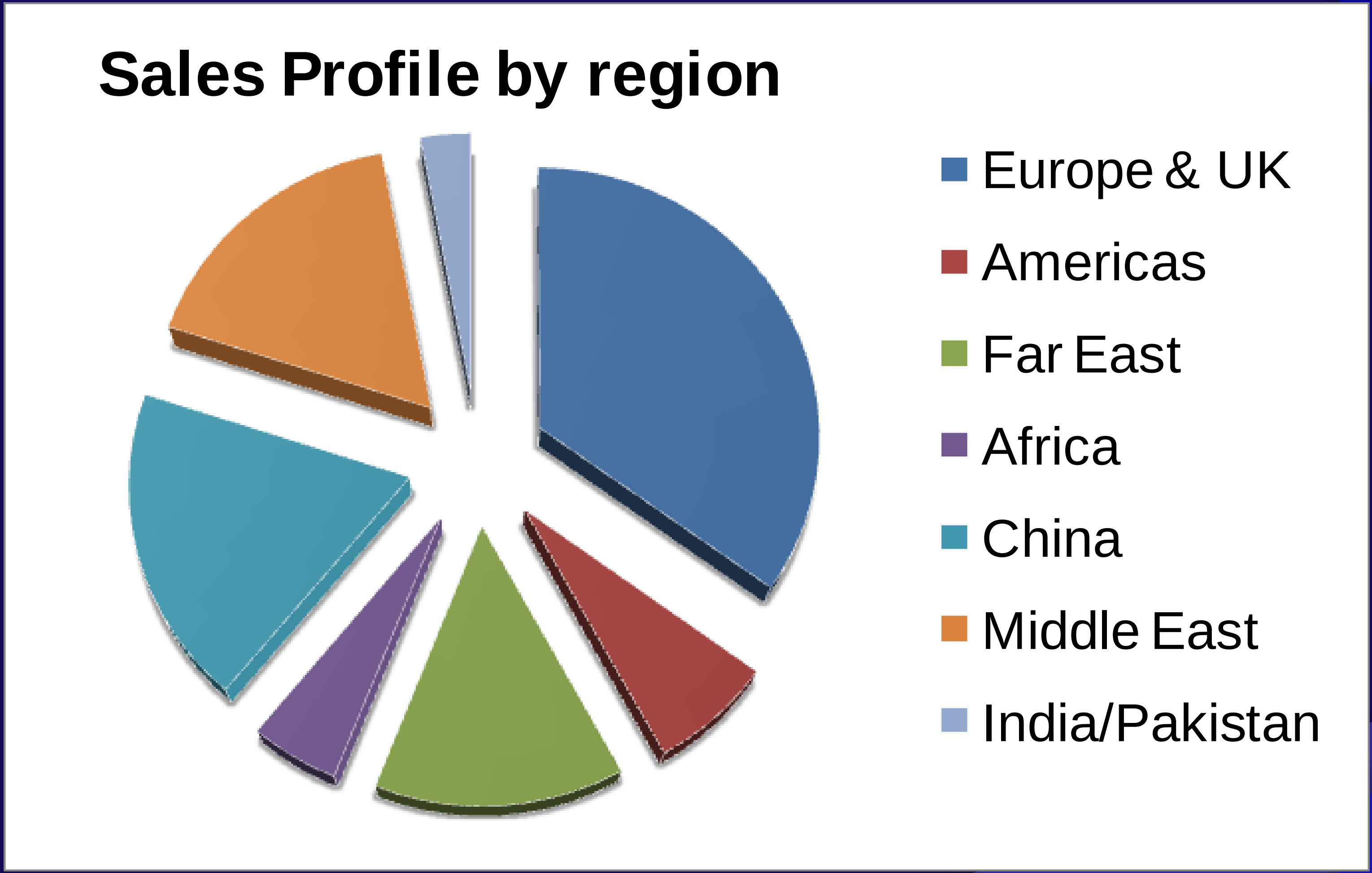
- UK's leading manufacturer of alloyed welding consumables
- Largest ranges of consumables from a single source

METRODE
WELDING CONSUMABLES

Industries


Sales Profile by Industry Sector
Offshore
Power
Petrochem
Standard Range inc R&M

Presence


Sales Profile by region
Europe & UK
Americas
Far East
Africa
China
Middle East
India/Pakistan

Dissimilar Welding of - P91 Steel

METRODE
WELDING CONSUMABLES

Dissimilar combinations

P91

Low alloy (P11/P22 etc.)

Austenitic/ Higher alloy

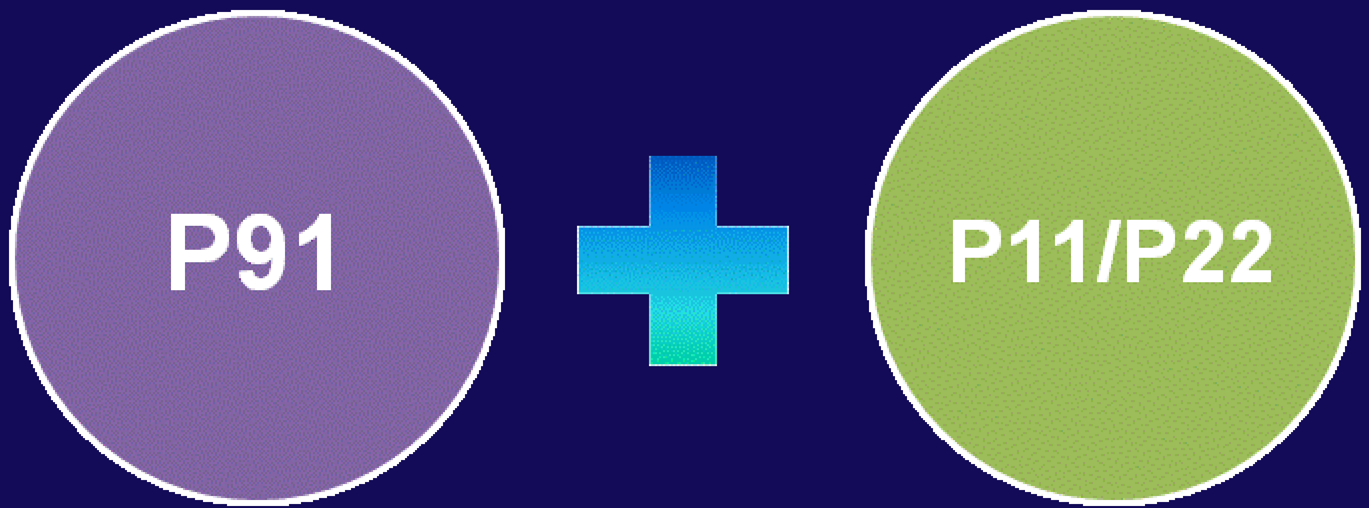
P92

Standards

AWS D10.8

BS 2633

CASE 1 – P91 to Low Alloy Steel



CASE 1 – AWS Recommendations

Matching Lower Alloy
P11/P22

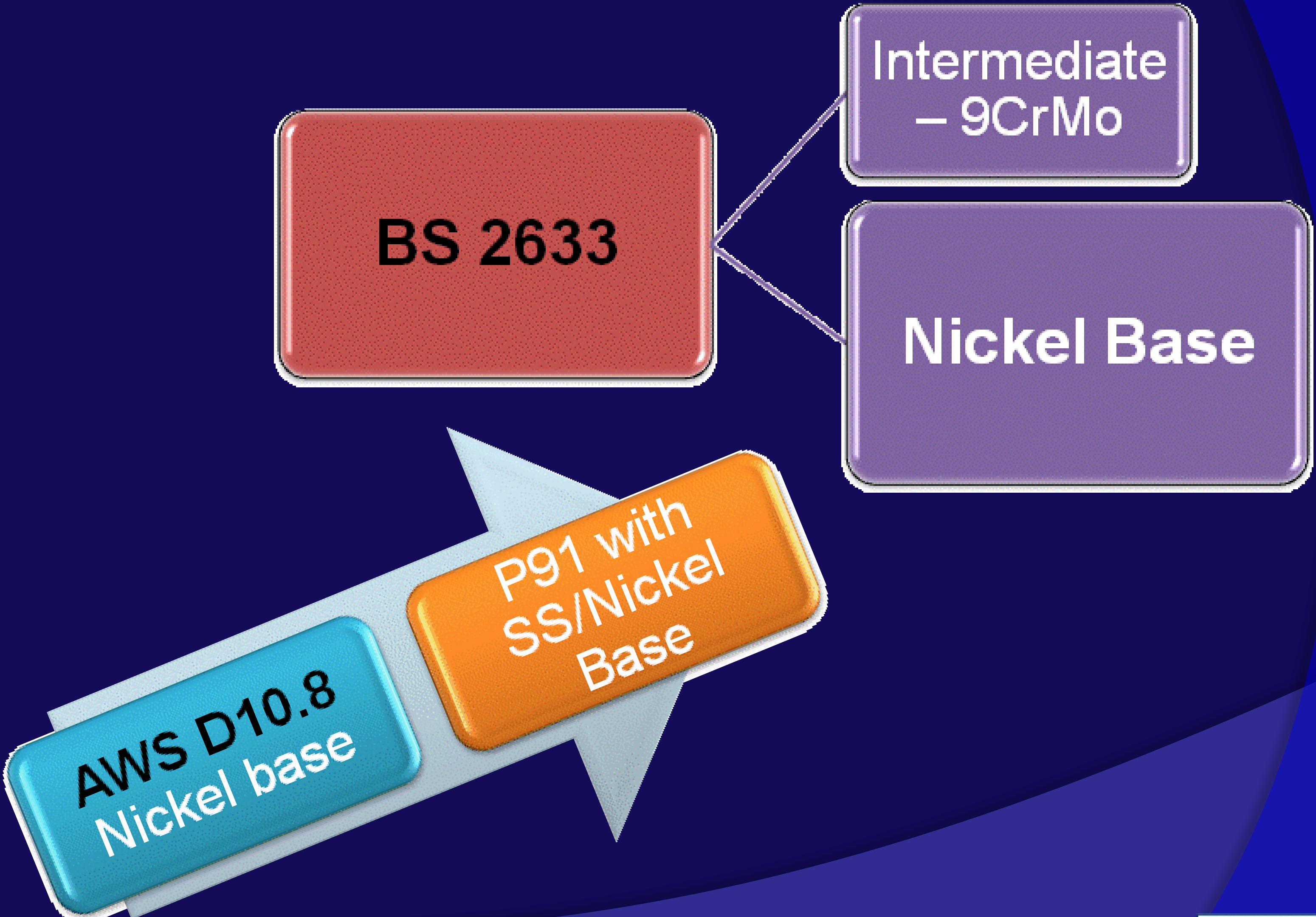
Matching Higher Alloy
P91

AWS D10.8

Intermediate Composition
5CrMo/9CrMo

Nickle base alloy

CASE 1 – BS Recommendations



METRODE WELDING CONSUMABLES

CASE 1 – Industrial Practice

Matching Lower Alloy

P11/P22

~~Matching Higher Alloy~~

~~P91~~

AWS D10.8

Intermediate Composition

5CrMo/9CrMo

~~Nickle base alloy~~

METRODE WELDING CONSUMABLES

Critical Welding Parameters - P91/P22

P22	P91
Preheat & Interpass	Preheat & Interpass
200-300	**200-300**

METRODE WELDING CONSUMABLES

Critical Welding Parameters - P91/P22

P22 - PWHT
680-720

P91 - PWHT
730-760

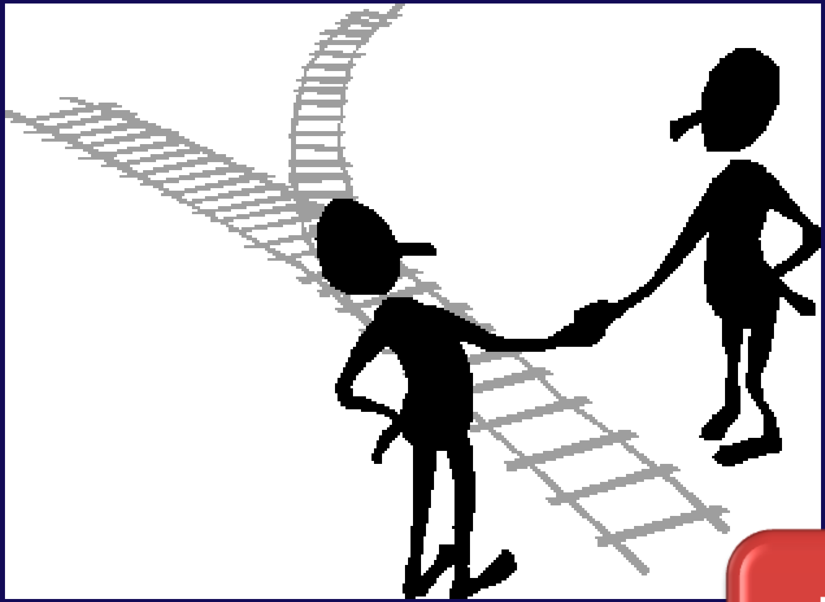
BS 2633

Highest temperature of Low Alloy

Lowest temperature of High Alloy

Creep properties

PWHT - P91/P22 – A Compromise



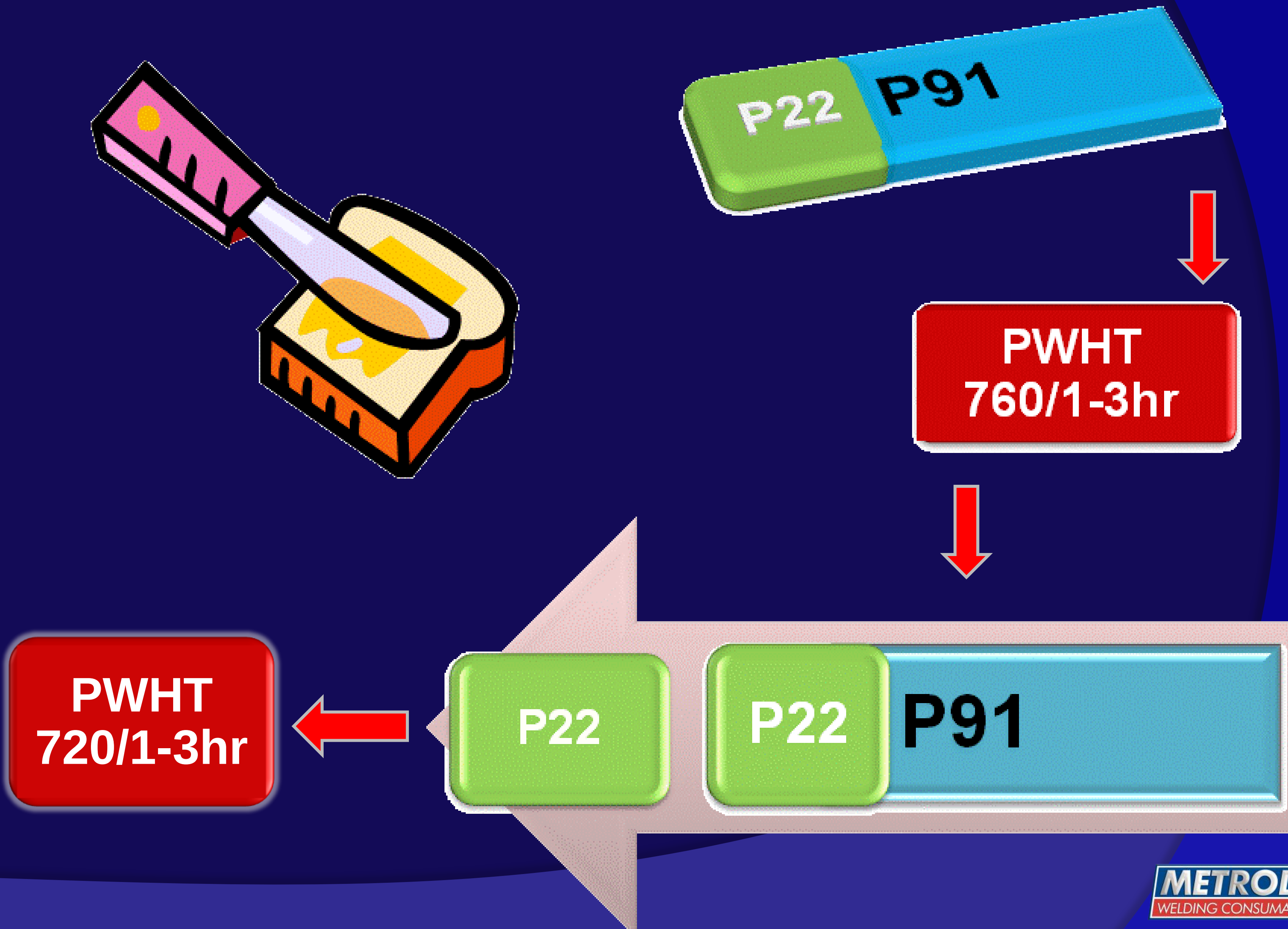
PWHT - P91/P22

720-730 / 1-3 hours

(Weld - 2CrMo/9CrMo)

METRODE WELDING CONSUMABLES

Critical Joints - P91/P22



METRODE
WELDING CONSUMABLES

Recommendations - P91/Low Alloy

Consumable - Low alloy Material (P11/P22)

↓

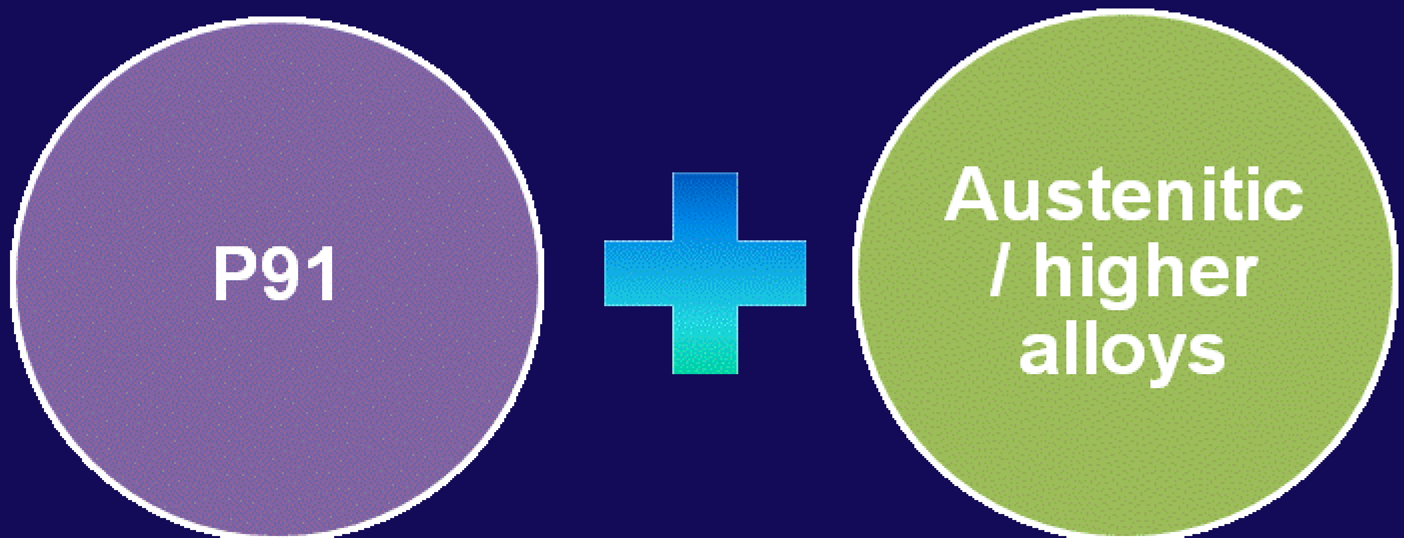
Direct Joint (Butter for critical joint)

↓

PWHT – Lower temperature of high alloy (730C)

METRODE
WELDING CONSUMABLES

CASE 2 - P91 to Austenitic/higher alloys



CASE 2 - P91 / Austenitic/higher alloys

Ni – Base
(182 type)

- Metallurgical Compatibility
- Creep Properties
- Ductility
- Service Life
- Carbon Migration

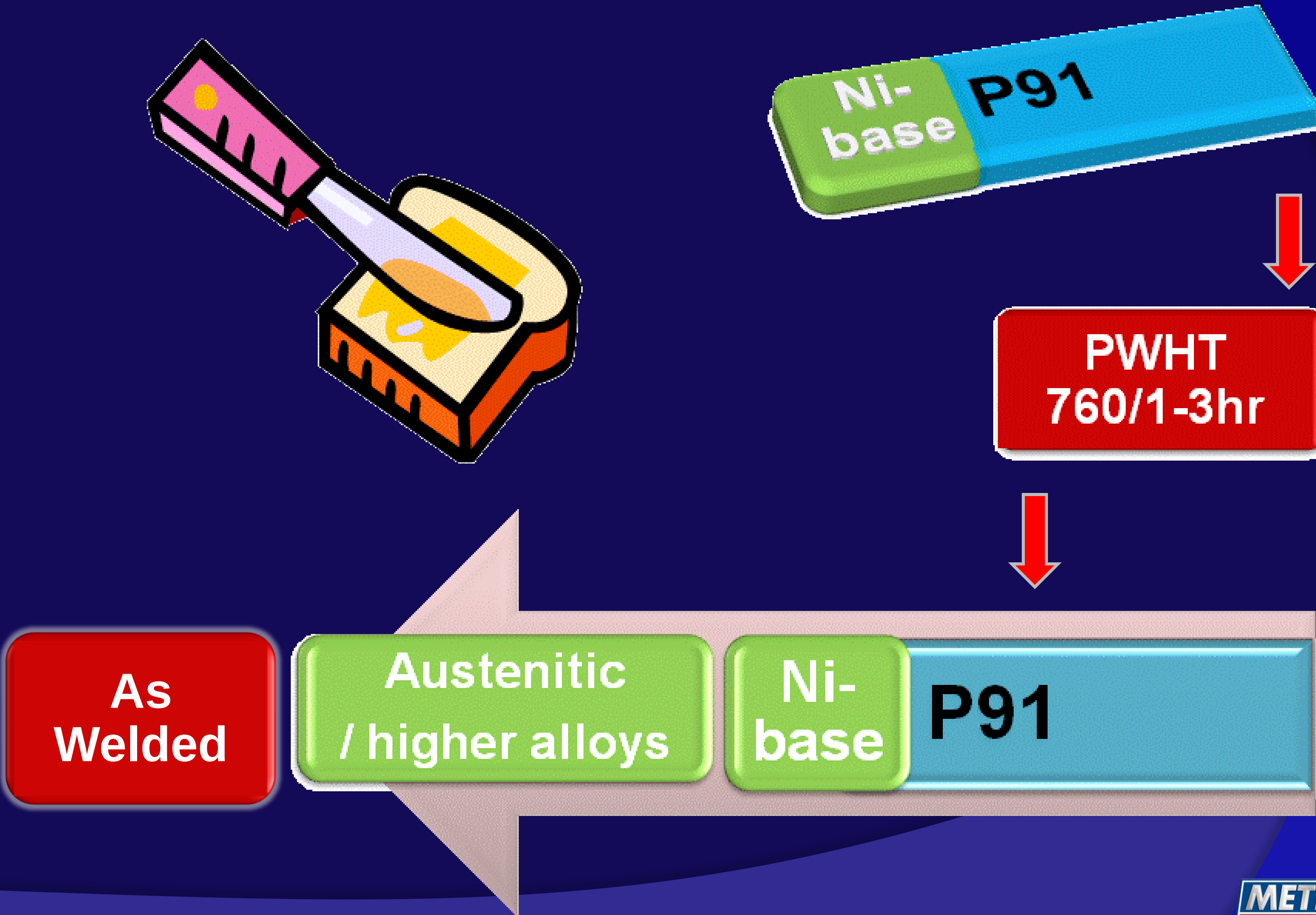
METRODE WELDING CONSUMABLES

PWHT - P91/Austenitic

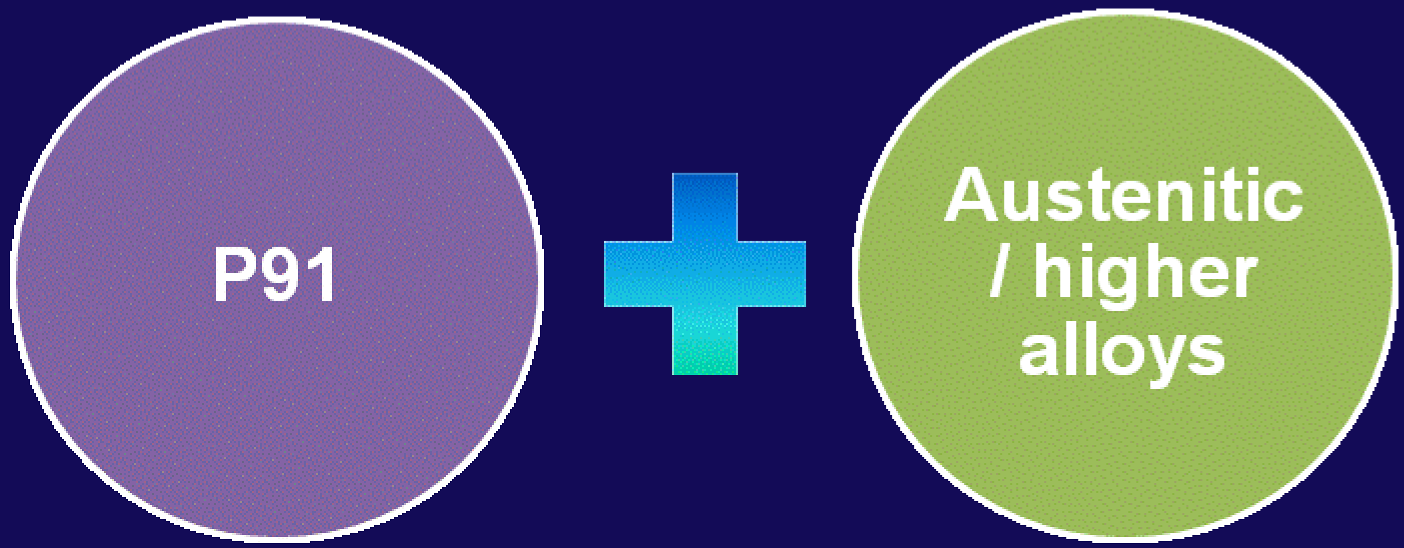
P91 /
Weld Metal

Austenitic /
Higher Alloys

PWHT - P91/Austenitic



CASE 2 – Issues & Alternative Material P87



METRODE WELDING CONSUMABLES

Issues – P91 /Austenitic/higher alloys

Microfissuring

Issues – P91 /Austenitic/higher alloys

Thermal Expansion

P91
7.0

Ni- Base
7.9

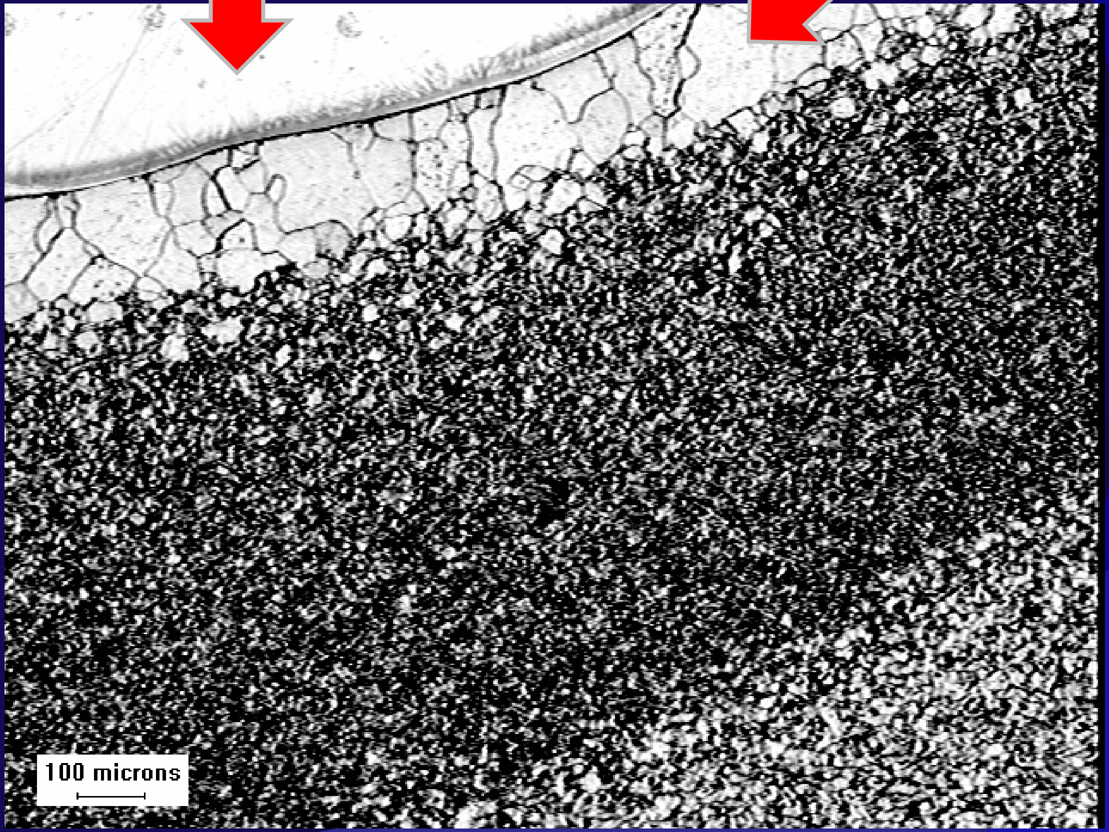
METRODE
WELDING CONSUMABLES

Issues – P91 /Austenitic/higher alloys

Filler Metal

Denuded Zone

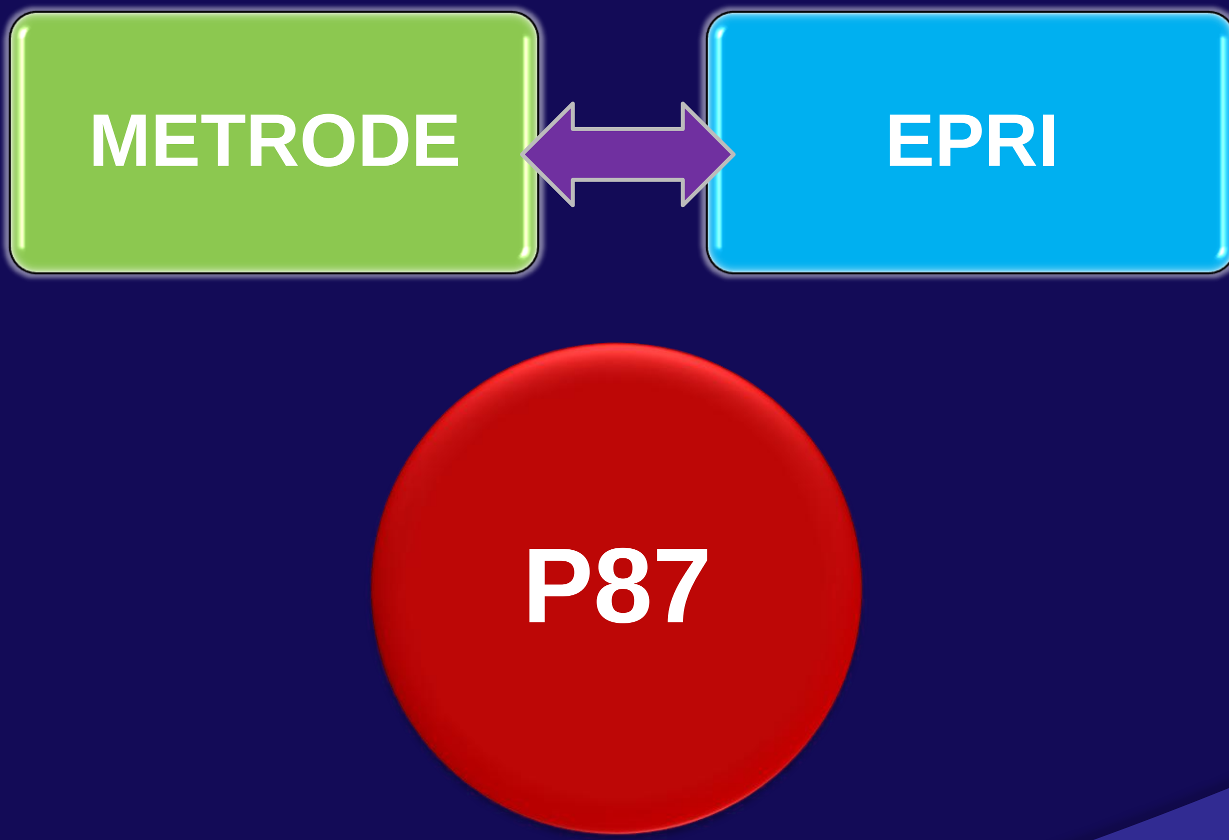
Carbon Migration



Issues – P91 /Austenitic/higher alloys

Carbide Formation

New Material – P87



P87 – Microfissuring

Elemental control to eliminate Microfissuring

Composition (weld metal wt %)

	C	Mn	Si	S	P	Cr	Ni	Mo	Nb	Fe
typical	0.1	1.5	0.3	0.008	0.008	9	Bal	2	1	38

METRODE WELDING CONSUMABLES

P87 – Microfissuring

Microfissuring Reduction

METRODE WELDING CONSUMABLES

P87 – Thermal Expansion

Thermal Expansion

P91
7.0

P87
7.5

METRODE
WELDING CONSUMABLES

P87 – Carbon Migration

1040C/2hrs + 980C/2hrs + 620C/4400hrs

P87

Ni-Base

METRODE
WELDING CONSUMABLES

P87 – Carbide Formation

Carbon Migration

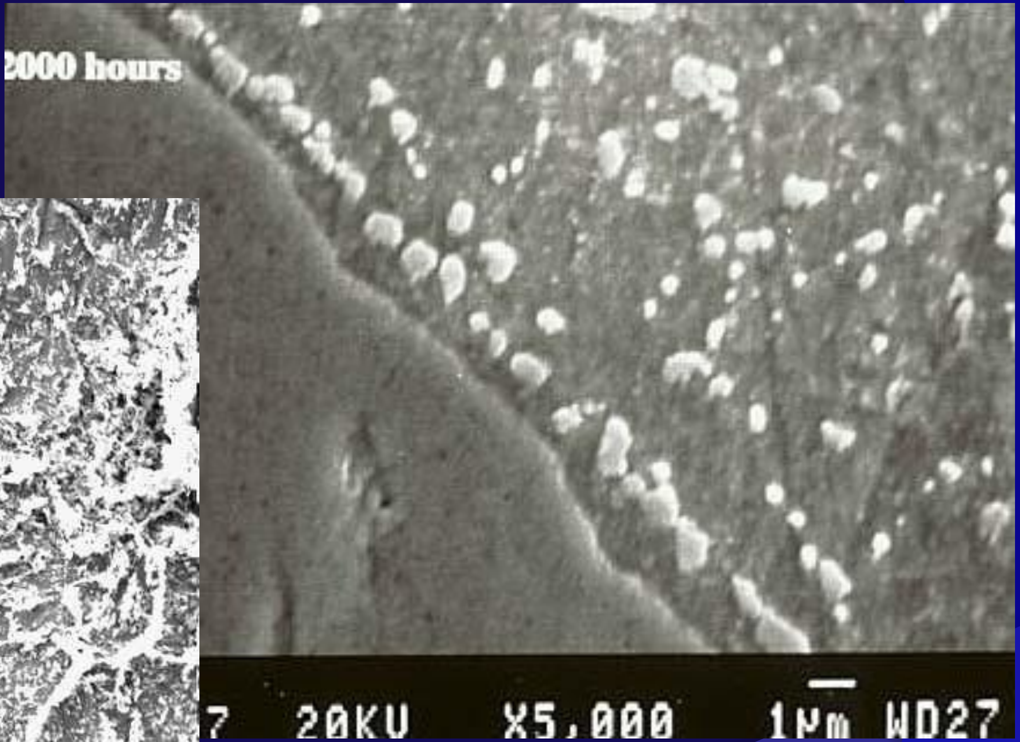
↔

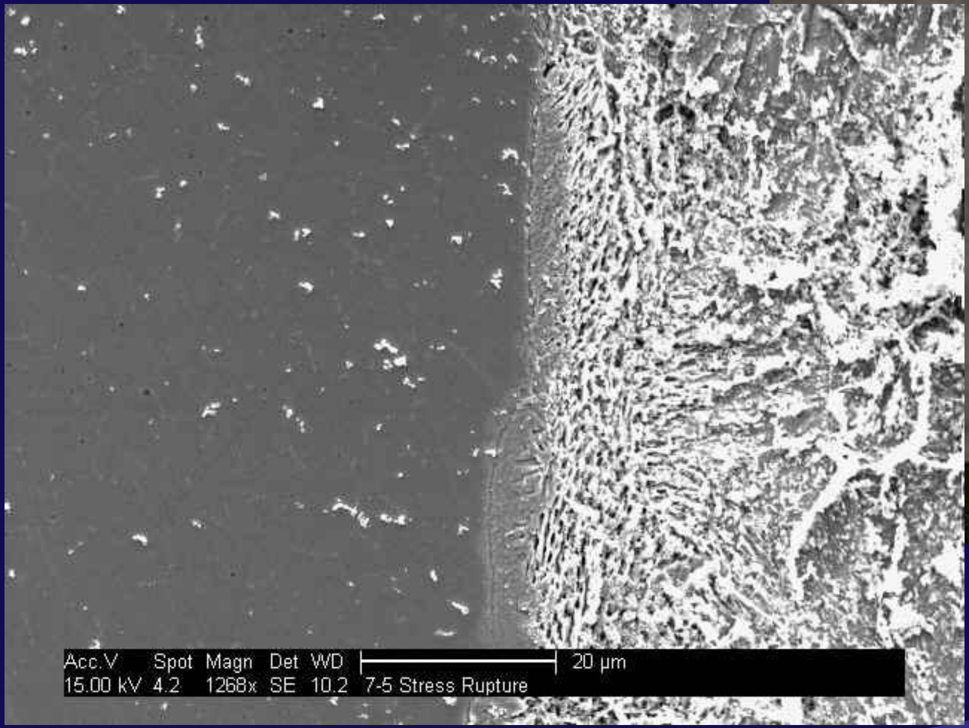
Carbide formation

METRODE
WELDING CONSUMABLES

P87 – Carbide Formation

4500 hrs
620 C





P87 – Mechanical Properties Ambient Temp.

P91 @ 68 (20C)

UTS = 85 Ksi (586)

YS = 60 Ksi (414)

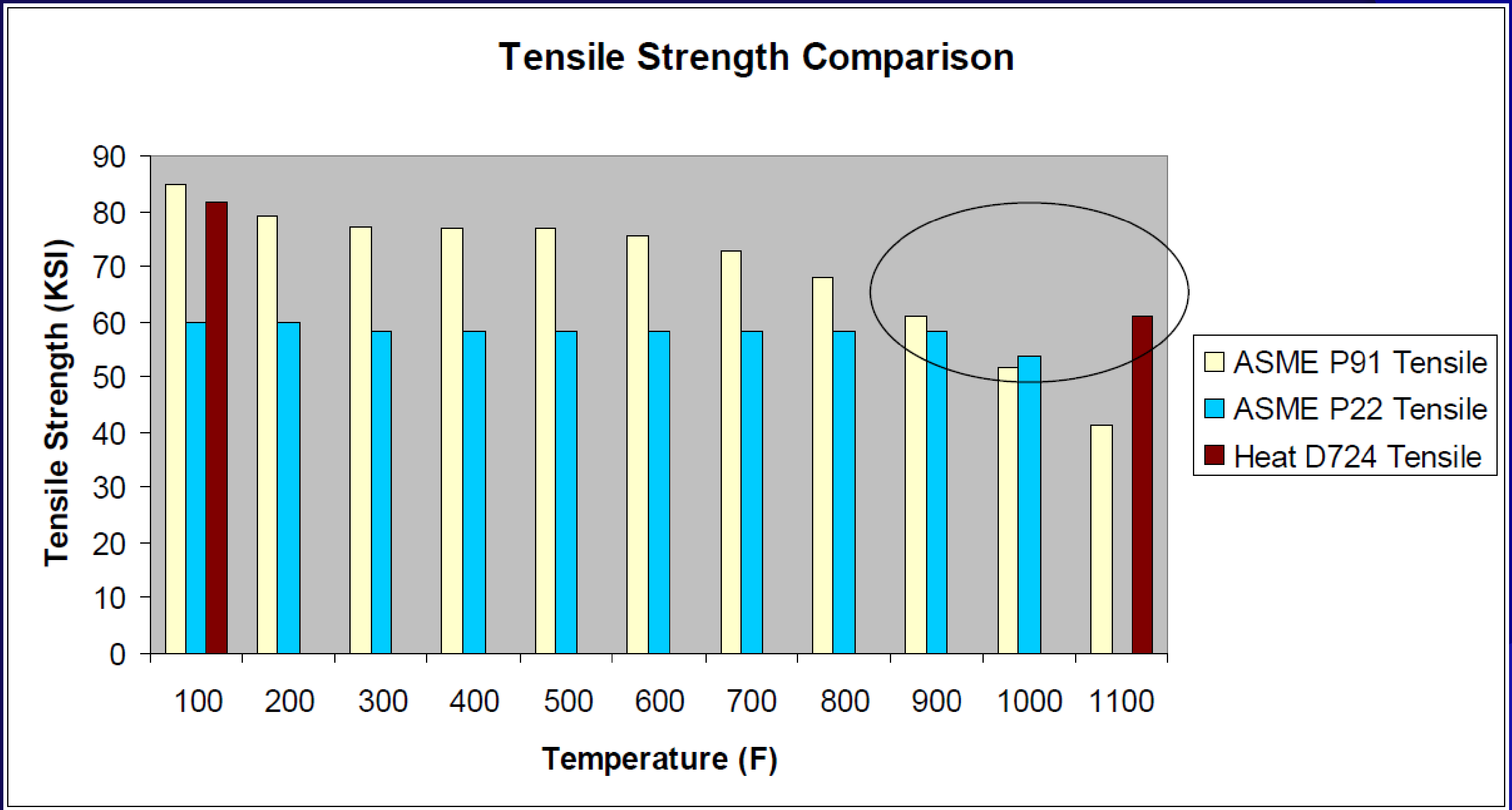
METRODE WELDING CONSUMABLES

P87 – Mechanical Properties Ambient Temp.

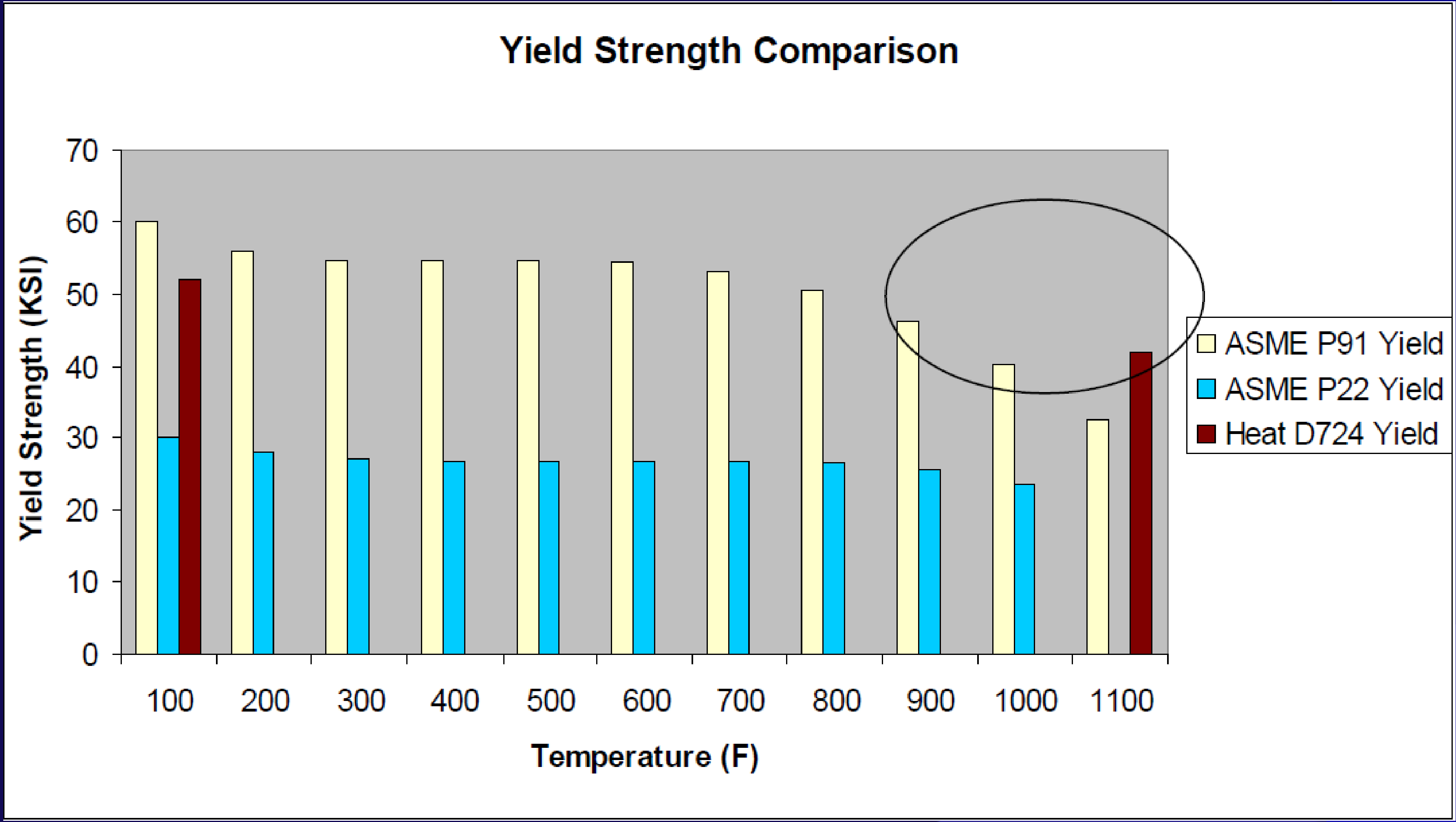
Comparative Strenght of Alloys (room temp.)		
Alloy	UTS	Yield Strength
	Ksi (MPa)	Ksi (MPa)
Heat D724	81.5 (562)	52 (359)
IN 182	80.0 (550)	NA
SA 335-P91	85.0 (586)	60.0 (414)
SA 376 TP304H	75.0 (517)	30.0 (207)
SA 335-P22	60.0 (414)	30.0 (207)

METRODE WELDING CONSUMABLES

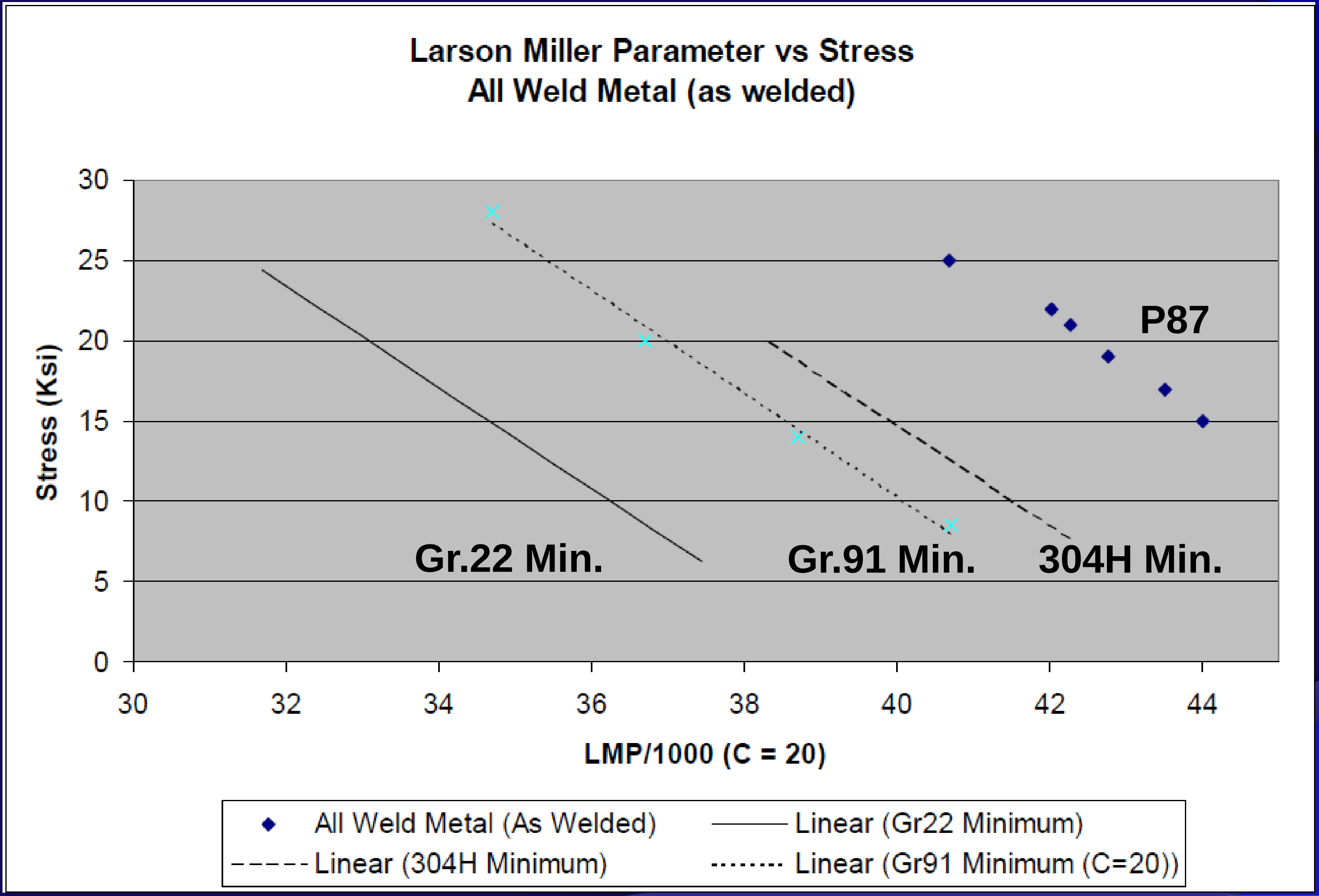
P87 – UTS vs. Temperature



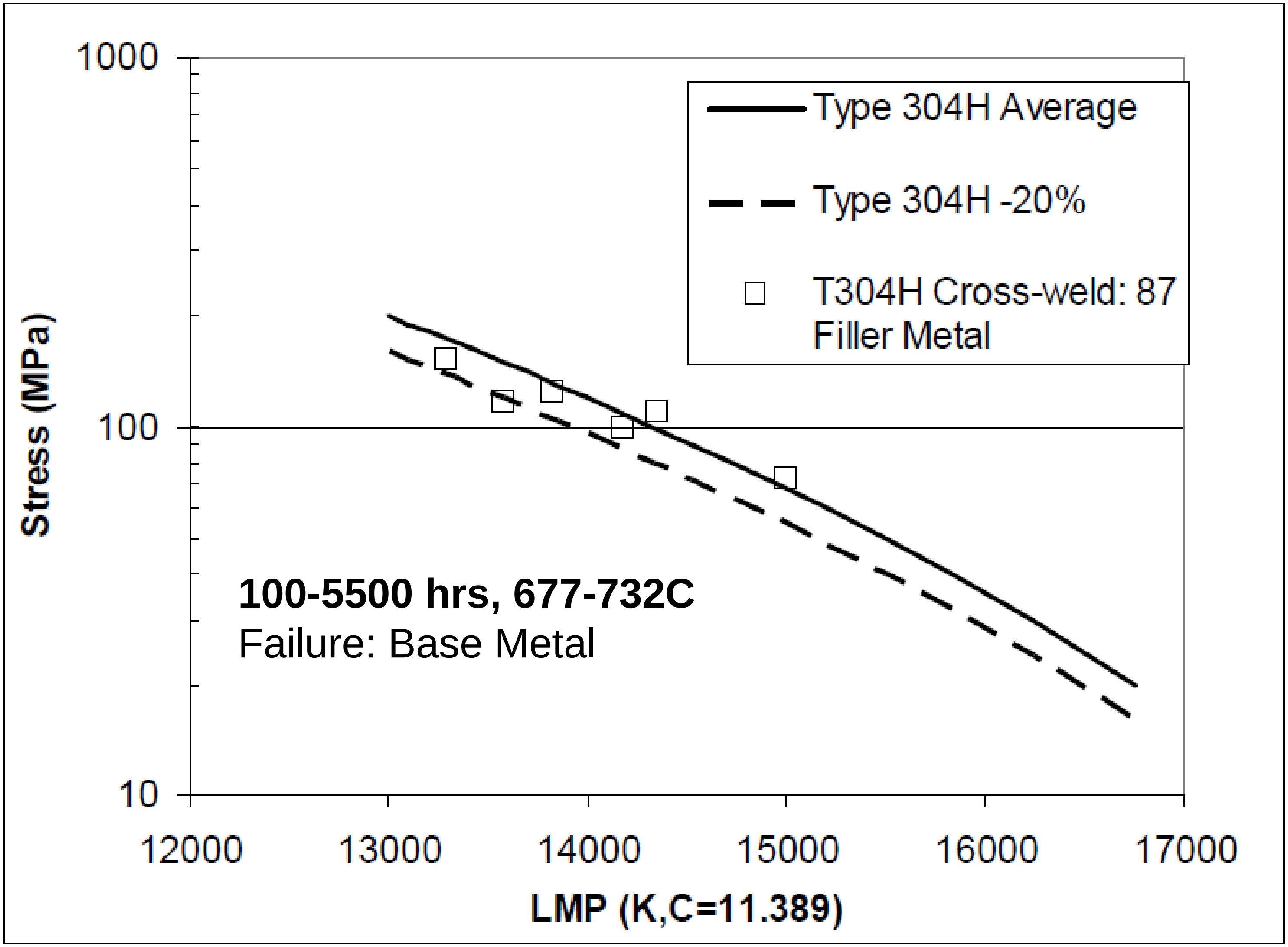
P87 – YS vs. Temperature



P87 – Creep Properties



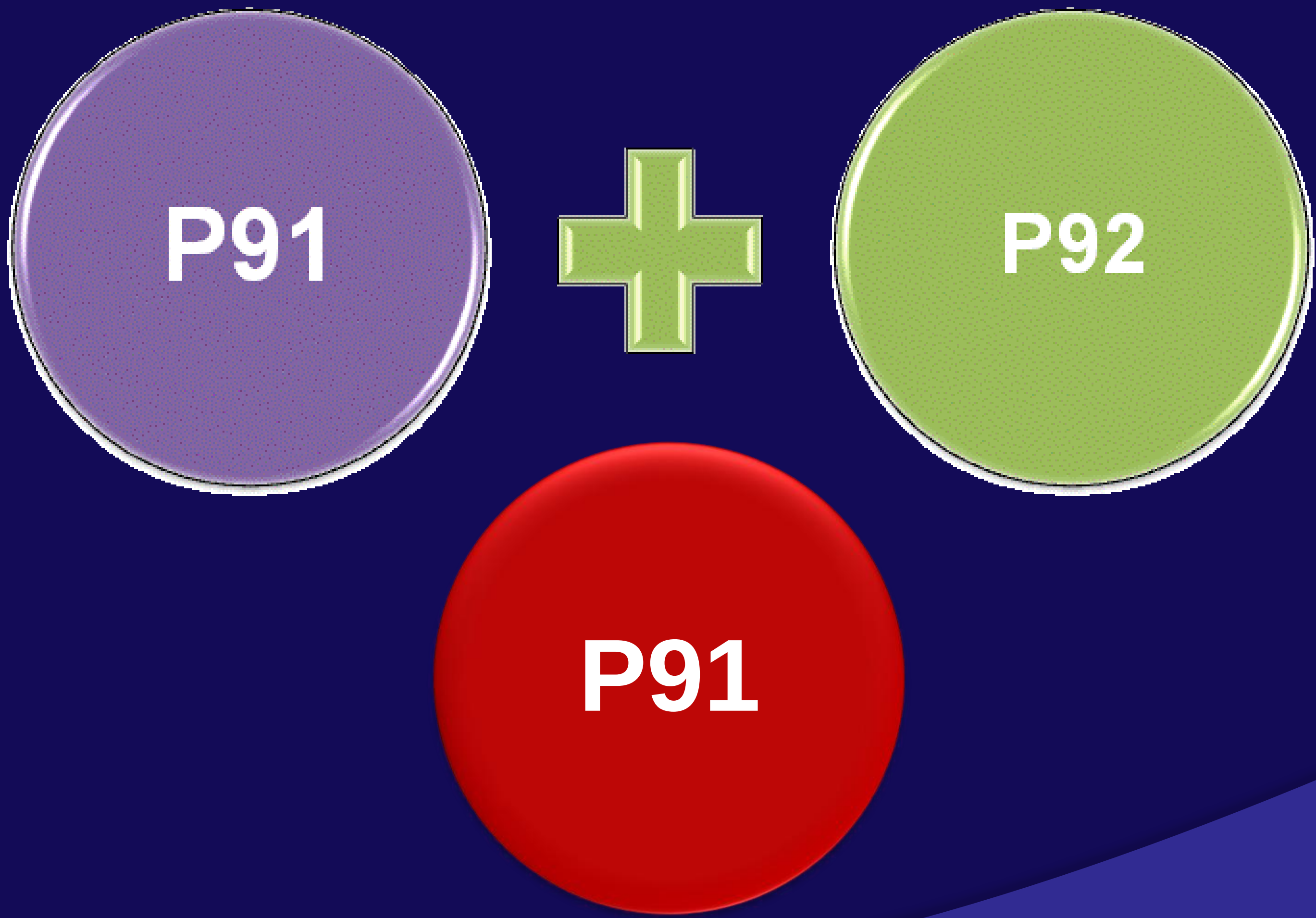
P87 – Creep Properties



P87 – Welding Consumable

METRODE
WELDING CONSUMABLES

CASE 3 - P91 to P92



Conclusions

P91 + P11/P22 → P22(P11) / 9CrMo → PWHT 720/1-3hr

P91 + Austenitic /higher → Ni-Base (182) ↔ P87

P91 + P92 → P91 → PWHT 760/1-3hr

METRODE WELDING CONSUMABLES

Critical Welding Parameters - P91/P22

Many Thanks

BACK

METRODE WELDING CONSUMABLES

Alstom

Indoctrination for the Fabrication and Assembly of Grade 91 Material and Hardness Testing

Rev. 2, August 6, 2010

ALSTOM

Alstom Grade 91 Indoctrination

- **The specifications and cautionary notes contained in this indoctrination represent requirements that supplement those contained in the ASME Boiler & Pressure Vessel Code Section I and Power Piping B31.1.**
- **These rules are necessary to ensure the satisfactory serviceability of any component fabricated by or for Alstom Power, Inc.**

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Alstom Grade 91 Indoctrination

- **What Alstom requires in the fabrication and assembly of their Grade 91 components.**

  - **Welders shall be qualified to ASME Section IX or EN codes**
  - **Minimum preheat for GTAW 300F (150C)**
  - **Minimum preheat all other processes 400F (205C)**
  - **Interpass temperature 750F (400C) maximum**
  - **Hydrogen bake welds over 16 mm thick and OD over 115mm after welding is completed**
  - **I.D purge with 100% argon for at least 2 passes**
  - **Post-weld heat treatment 1350-1425F (730-775C) for 1 hour per inch of thickness, 30 minutes minimum**
  - **Hardness test results shall be documented**
  - **Records are maintained**

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Permitted Welding Processes

- **GTAW - Gas Tungsten Arc Welding**
- **SMAW - Shielded Metal Arc Welding**
- **SAW - Submerged Arc Welding**

- GMAW/FCAW - Gas Metal Arc Welding/Flux Cored Arc Welding, shall only be permitted for welding Grade 91 or attachments to Grade 91 when approved by Alstom. See Slides 11 and 12 for acceptable welding consumables.
- **Welding consumables shall conform to ASME Code Section II Part C or equivalent EN Standards.**
- **Actual material certifications are required for all electrodes & wire. No “typical” certificates will be accepted.**

Welders Performance Qualification Test

- All welders shall have passed a weld test in accordance with ASME Code Section IX, EN 287 or IBR as applicable. The welder's test shall be witnessed by the Notified Body for PED and Competent Authority for IBR projects.

- Confirm that welders have been working within the initial range of qualification. This shall be confirmed every six month of being assigned to production welding for each process. If the IBR Code welder has not been engaged in welding in the past 3 months, he must be retested. Check continuity records.

- Welders continuity records shall be the fabricators/assemblers responsibility and shall be available for review by Alstom personnel.

Filler Metal

- **Filler metal permitted for welding Grade 91 to 91 material for ASME and IBR Codes:**
  - **ER90S-B9- GTAW**
  - **E9015,16 or 18-B9- SMAW**
  - **ER90S-B9- GMAW**
  - **E91T1-B9- FCAW**
  - **EB9- SAW**

Filler Metal

- **Filler metal permitted for welding Grade 91 to 91 material for EN Standards:**

  - **W CrMo91** — **141-GTAW**
  - **E CrMo9 B 42 H5** — **111-SMAW**
  - **Cormet M91 (MCW)** — **131-GMAW**
  - **Metrode Supercore F91** — **137-FCAW**
  - **S CrMo91** — **12-SAW**

Filler Metal for Welding Grade 91 to 91

- All welding filler metal shall be purchased with the combined nickel and manganese content not exceeding 1.2% and the nitrogen content shall be at least (0.5 x Aluminum content + 0.03)%.
- Actual material chemistry certs for all Grade 91 consumables, shall be submitted to Alstom personnel for review.
- Any deviations from these requirements will require Alstom's approval.
- "G" Grade welding consumables are not acceptable.

Alstom Grade 91 Indoctrination

- **Procurement**
- **Storage**
- **Control**

Welding Material Control System

- Fabricator/Assembler shall have a documented procedure for procurement/storage of filler metals.
- Purchase only welding electrodes that are approved by ASME Code, Section II Part C or equivalent EN standards.
- Purchase coated electrodes in sealed containers.
- Store low hydrogen electrodes in a clean dry area.
- Store open containers in stabilizing or portable ovens at a temperature between 250F - 350F (120-175C).
- Damaged or wet electrodes must be destroyed.

Welding Material Control System

- Identify all production welds with their appropriate filler metal.
- Filler metal to correspond to pressure parts being welded.
- Dispense filler metal from a restricted and controlled area.
- Issue a functional portable storage oven to welders when issuing electrodes.
- One or two types of filler metal with the same suffix may be issued to a welder at a time. Example: GTAW/SMAW, suffix B9.
- Unused electrodes shall be returned to the dispensing area at the end of the work period.
- All dispensed filler metal shall be documented in a log.

Eliminate poor housekeeping of weld rod stubs on the shop floor and open box of rods on beam.

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Welding Preparations

- All surfaces to be welded shall be free of any contaminants (paint, loose rust, oil, grease, dirt, debris, and moisture).
- Grit blasting, if employed, shall be performed using non-silica media.
- For field welds, the welding area shall be protected from rain, wind, and other weather related elements until all welding, inspection and post weld heat treatment activities have been completed.

All welding machines shall be calibrated annually

- Ground cables from welding machines shall be attached directly to the part being welded. Pay close attention to welding leads to prevent them from arcing against the Grade 91. Welding leads or electrical cords shall not be run across the Grade 91 materials.
- A safe and preventative practice is to ensure welding leads, electrical cords, and lights, are up and out of the way, and secured with a non-conductive material.

Arc Strikes

- It is imperative that all Arc Strikes be avoided.
- If for any reason the base material is subjected to an arc strike, or accidentally welded upon, a Nonconformance Report (NCR) shall be issued to Alstom immediately.
- No further work shall be performed on the component until dispositioned by Alstom personnel.
- It is generally advised that the base material adjacent to the work area should be wrapped with fire-retardant barriers to avoid accidental arc strikes.

Fit-up Bridges

- If bridges are used for fit-up, they shall be made of Grade 91 material and welded with Grade 91 filler metal.
- Any weld areas associated with these bridges shall be contained within boundaries prescribed for preheating and post weld heat treatment.
- All bridges that are tack welded on the OD of the pipe shall be inspected with either MT or PT after the tack welds have been removed.

Preheating

- Preheat shall be applied using electric resistance elements, controlled, measured and monitored over the entire soak band defined by the relevant code or 3” (75mm) on either side of the weld, whichever is greater. Results of preheat shall be documented.
- Flame preheating may be used, provided the following conditions are met:
  - Only low temperature, neutral flame is permitted with a rosebud torch with propane gas. Monitoring shall be provided at all times.
  - At no time shall the metal temperature at any location exceed 1400F (760C). Cutting torches are prohibited.
- The preheat temperature shall be a minimum of 300F (150C) for the gas tungsten arc welding process and shall be a minimum of 400F (205C) for all other processes.

Preheat maintenance

- **Preheat shall be maintained throughout the entire welding cycle, including tack welds and fit-up welds. Preheat may only be interrupted provided all of the following conditions are met:**
  - **A minimum weld material deposited in the weld groove of 3/8" (10mm) or 25% of the weld joint thickness, whichever is greater.**
  - **A hydrogen bake shall be performed immediately**
  - **A visual examination for cracks is performed prior to resuming welding.**
  - **The required preheat is re-established prior to resuming welding.**
  - **Results of preheat shall be documented.**

Interpass Temperature

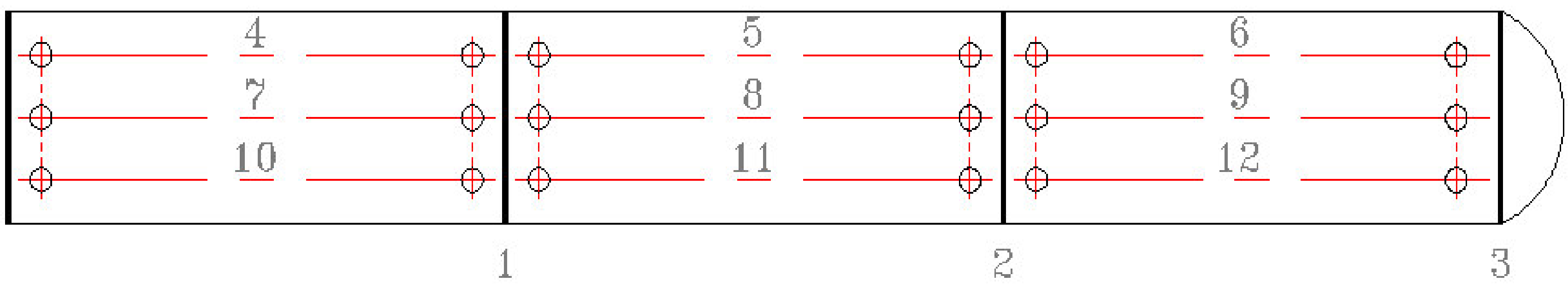
- Interpass temperature shall not exceed 750F (400C).
- The interpass temperature shall be measured and monitored at the last deposited weld bead of the weld joint.
- The interpass temperature shall be measured by the use of temperature indicating crayons, optical pyrometers, thermocouples with calibrated chart recorders, potentiometers or an equivalent method that does not harm the base material or deposited weld metal.
- Result of the interpass temperature shall be documented.

Fabrication of Complex Components

- Preheat segment or entire component to be welded to 400F (205C), depending on quantity of joints being welded.
- The completed welds shall be maintained at 200F (95C) until all welding on the entire component is completed.
- Care shall be to minimize any loads to the component before hydrogen bake or post weld heat treatment has been performed.
- If post weld heat treatment is delayed for more then 8 hours, perform the hydrogen bake.

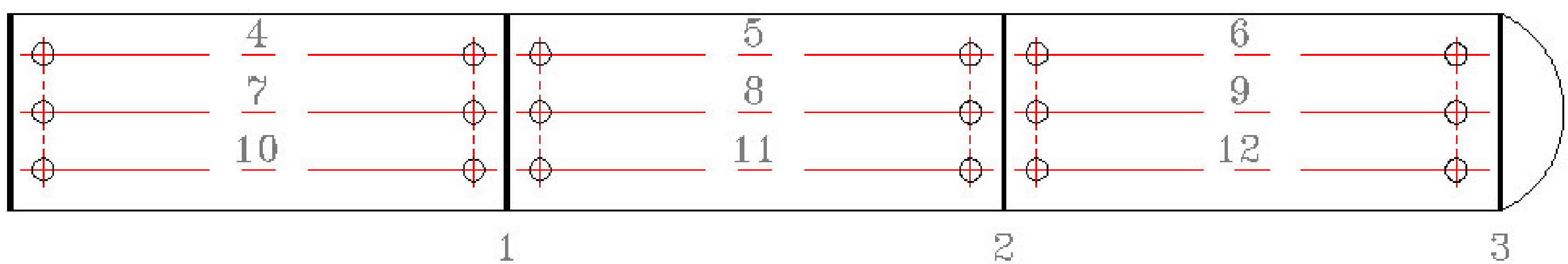
Suggested Welding Sequence – (6 pages)

- Preheat to 400F (205C) and weld joints 1, 2, and 3 following the Welding Procedure Specification.
- Complete welds 1, 2, and 3.
- Let cool to below 200F (95C) and post weld heat treat welds 1, 2, and 3 prior to drilling.



Drilling of Component

- Move header to drilling machine, mark and drill holes.
- Preheat to 400F (205C) and weld joints 4, 5, and 6 following the Welding Procedure Specification.
- Complete welds 4, 5, and 6.
- Maintain welds 4, 5, and 6 at 200F (95C) after welding and until post weld heat treatment.



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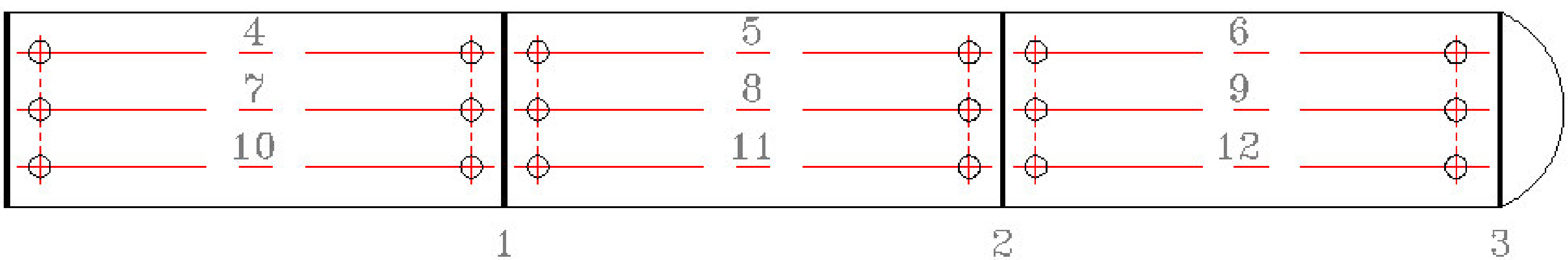
Continue Welding

- Rotate header to 1G position to optimize welder access.
- Preheat to 400F (205C) and weld joints 7, 8, and 9 following the Welding Procedure Specification.
- Complete welds 7, 8, and 9.
- Maintain welds 7, 8, and 9 at 200F (95C) after welding and until post weld heat treatment.



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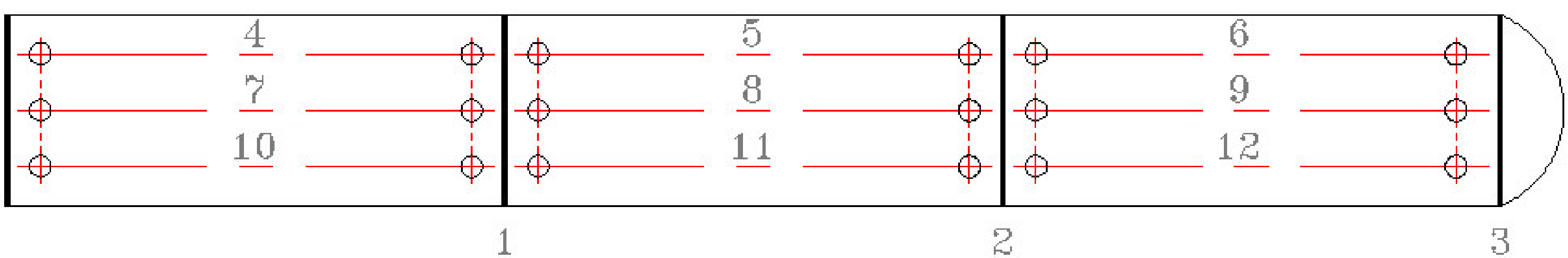
Continue Welding

- Rotate header to 1G position to optimize welder access.
- Preheat to 400F (205C) and weld joints 10, 11, and 12 following the Welding Procedure Specification.
- Complete welds 10, 11, and 12.
- Maintain welds 10, 11, and 12 at 200F (95C) after welding and until post weld heat treatment.



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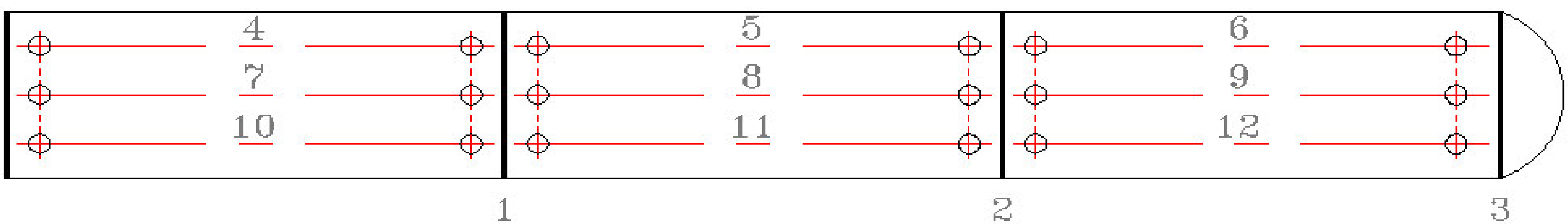
Hydrogen Bake

- Maintain entire component at 200F (95C) until post weld heat treatment.
- If post weld heat treatment is delayed for 8 hours or more and 200F (95C) cannot be maintained, perform a hydrogen bake on the entire component, see figure 1, slide 34.
- If 200F (95C) has been maintained until PWHT, hydrogen bake is not required.



Hydrogen Bake

- **After all welds are completed on large components, or after the completion of a single weld, the welds shall be cooled in still air to below 200F (95C) prior to hydrogen bake.**
- **If it is not possible to perform post weld heat treatment within 8 hours after the completion of the weld, a hydrogen bake shall be performed on the weld joint. Tubes and pipes with the outside diameter up to 4.5" (115 mm), inclusive, and wall thickness up to 5/8" (16 mm) are exempt from hydrogen bake, see figure 1, slide 34.**
- **Hydrogen bake shall NOT be interpreted as a post-weld heat treatment.**

Hydrogen Bake

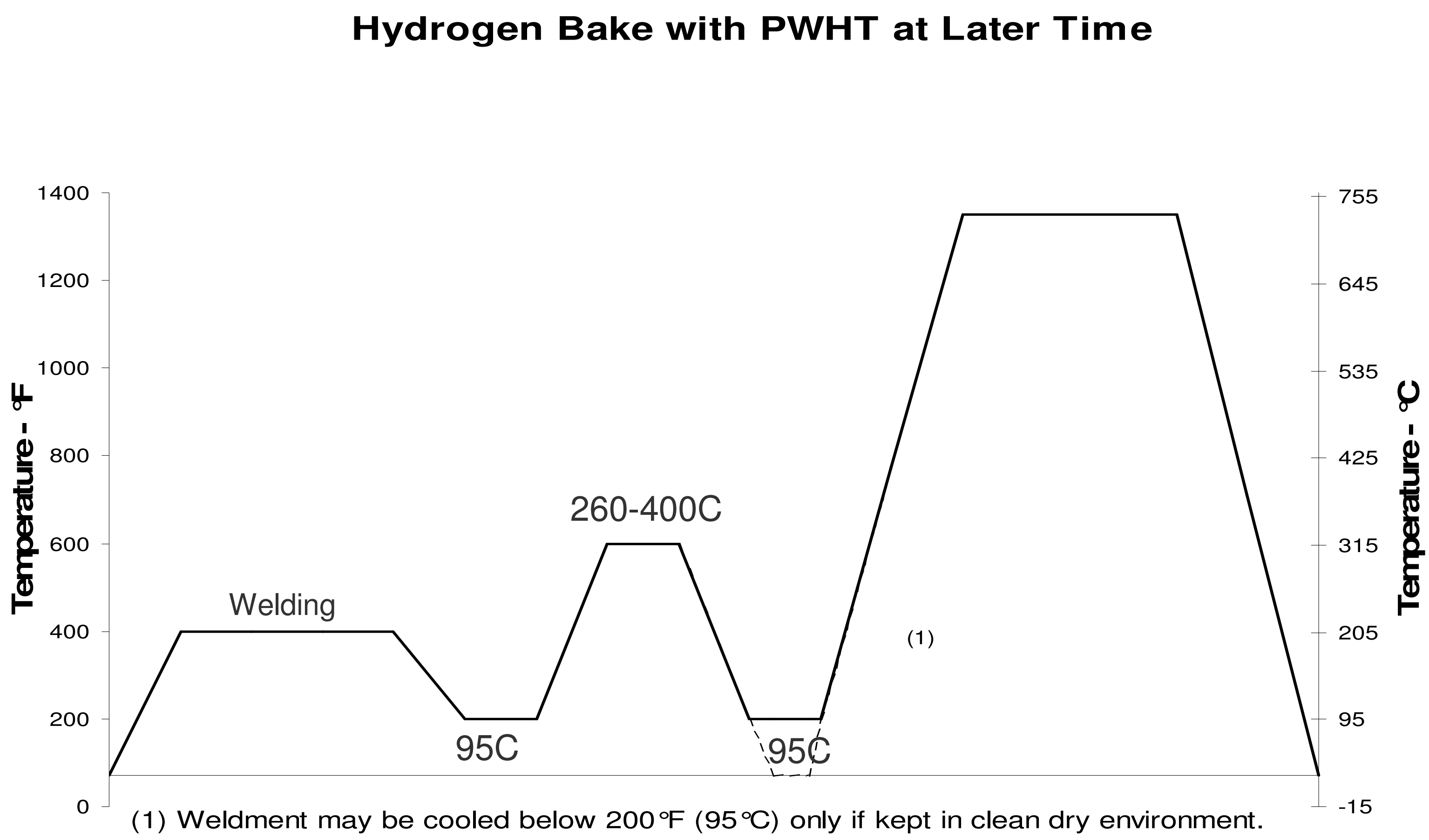
- Hydrogen bake shall be either by furnace or localized heating. If localized heating is used, electric resistance elements shall be used as the heat source covered by insulation.
- The temperature shall be raised to 500-750F (260-400C) and held for one hour per inch of thickness, up to a maximum of four hours, but in no case less than 30 minutes and then allowed to cool in still air to ambient temperature.

Hydrogen Bake

- **Hydrogen bake shall be monitored by thermocouples with calibrated chart recorders, optical pyrometers or temperature indicating crayons.**
- **Results of Hydrogen bake shall be documented. See Figure 1, next slide.**

Alstom Grade 91 Indoctrination

Figure 1



Hydrogen Bake

- Following any hydrogen bake, the components shall be kept dry until post weld heat treatment has been performed.
- Dry means that at no time shall the weld come into contact with liquids, including atmospheric condensation (water). If this is not possible, the component shall be maintained at a temperature above 200F (95C).
- Electric resistance elements shall be used to ensure the component remains dry.

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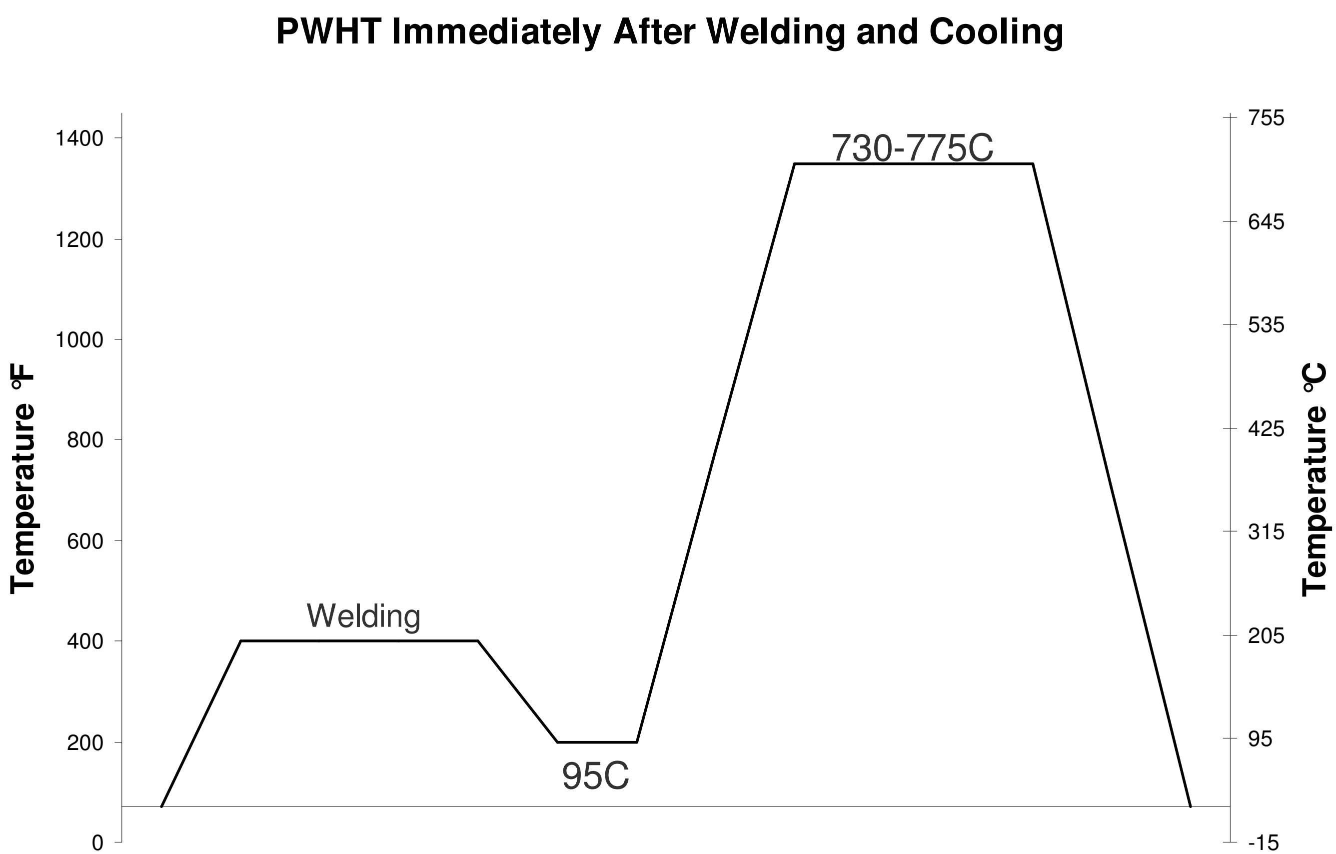
External and Transport Loads

- The weldment shall not be subjected to any applied loads in the as-welded condition.
- Do not use come-a-longs, air bags, wedges, hammers or anything to move this material for fit-up.
- Do not lift ground assembled parts into position in the unit before post weld heat treatment has been complete on the welds on the ground.
- Care must be used to limit any stresses on welds during transport prior to post-weld heat treatment

Post Weld Heat Treatment

- If localized post weld heat treatment is utilized, the resistance pads shall be wrapped completely around the entire circumference of the component and shall be covered with insulation.
- Direct flame heating for post weld heat treatment shall not be permitted.
- Calibrated recording devices shall be used to record the time at temperature during all PWHT, including both heating and cooling cycles. See Figure 2, next slide.

Figure 2



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Post Weld Heat Treatment

- **Post weld heat treatment shall consist of heating to the temperature of 1350-1425F (730-775C) for one hour per inch of thickness, but in no case less than 30 minutes and allowed to cool in still air.**
- **All thermocouples shall be insulated from direct contact with electric resistance elements with thermocouple putty or insulation pads.**
- **Refer to Alstom Standard 2-2004-10 for additional post weld heat treatment for Grade 91 material welded to other materials.**

Post Weld Heat Treatment

- The temperature of the weldment shall not exceed 1425F (775C) for any reason during the Post Weld Heat Treatment.
- If the temperature exceeds 1425F (775C) for any reason, a deviation from contract requirement shall be issued to Alstom immediately.
- No further work shall be performed on the component until dispositioned by Alstom personnel.

Post Weld Heat Treatment

- After the initial post weld heat treatment of one hour per inch of thickness for the Grade 91, additional welding may be necessary to complete the component.
- If additional welding is required, such as seal welds, socket welds or other attachment welds of .375” (10 mm) or less, the weldment shall be post weld heat treated at the temperature of 1350-1400F (730-760C) for a minimum of 30 minutes.

Post Weld Heat Treatment

- **All P-15E Group No. 1, Grade 91 components that have been welded shall not be subjected to any forces to align, adjust or straighten before a post-weld heat treatment has been completed.**
- **Headers that are completed and subject to straightening prior to tube-to-header welding, shall be given an interim PWHT at 1350-1400F (730-760C) for one hour per inch of thickness, but in no case less then 30 minutes.**

Post Weld Heat Treatment

- **The heating for aligning, adjusting shall be using electric resistance elements controlled by thermocouples; *torches are not permitted.***
- **When heating is performed the metal temperature must be kept below 1425F (775C) and documented.**
- **Any straightening operation shall be documented.**

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Weld Inspection

- If radiography, ultrasonic testing, magnetic particle testing or liquid penetrant testing is performed prior to post weld heat treatment, a hydrogen bake shall be performed prior to performing any testing.
- If liquid penetrant testing or ultrasonic testing is performed prior to post weld heat treatment, the solvent type method shall be used in lieu of water-soluble method.
- It is important that all residue be removed from the component after the testing is completed.

Lifting Devices

- Lifting devices used for Grade 91, such as slings and chokers shall be fabricated from non-abrasive material, nylon or mesh is acceptable.
- If wire rope slings are used, precaution shall be taken to prevent slippage and gouging of the material.
- No lifting device or portion of a lifting device, such as lugs, are to be welded to any Grade 91 material.

After Painting and/or Prior to Shipping

- **All Grade 91 completed components shall be stenciled with the words:**

GRADE 91 MATERIAL

DO NOT STRIKE ARC

- **Use bright contrasting paint color for stenciling.**

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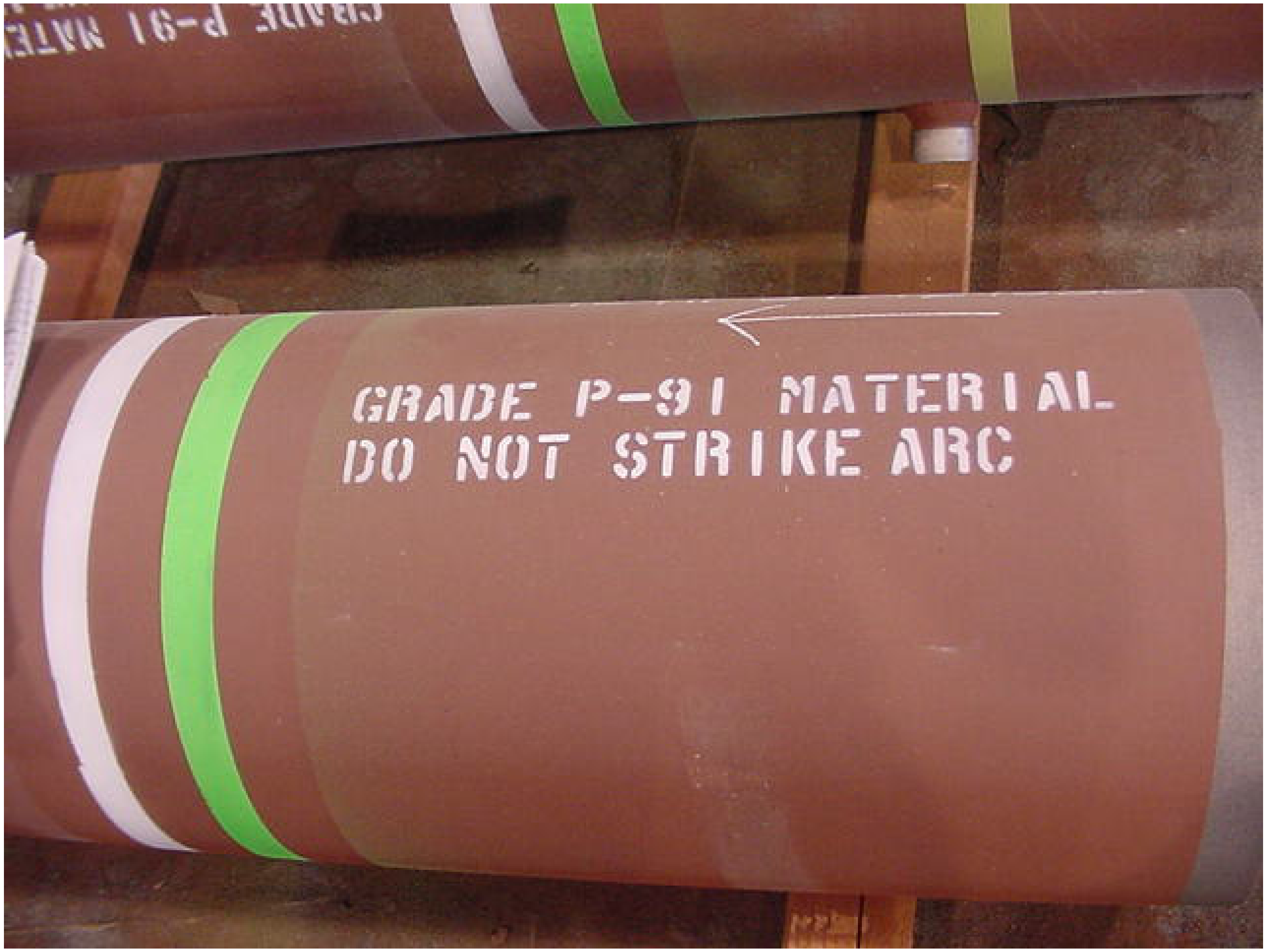
Alstom Grade 91 Indoctrination



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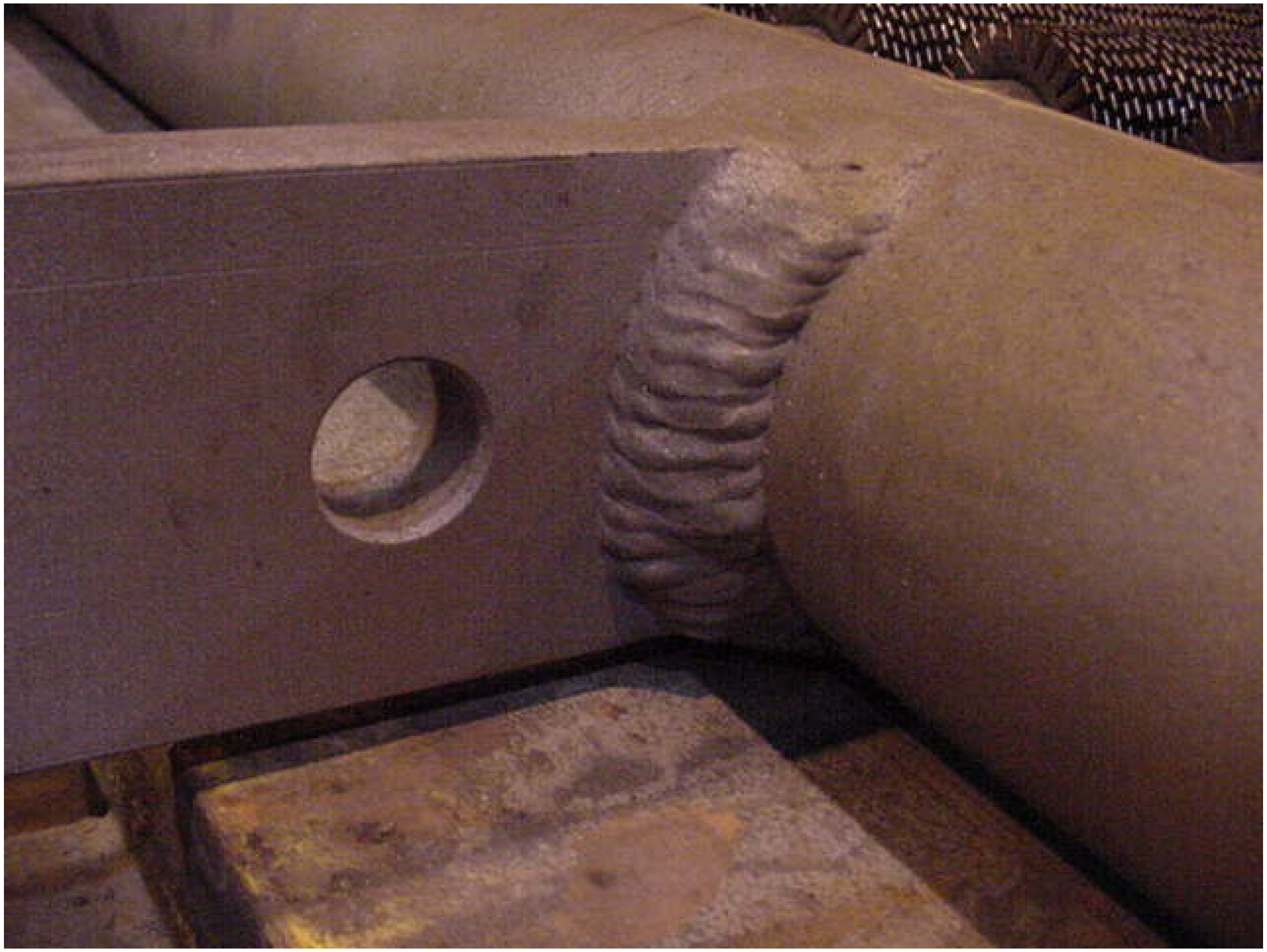
Weld weave bead shall not exceed 6 times core wire diameter.

Alstom Grade 91 Indoctrination

Weld weave bead shall not exceed 6 times core wire diameter.



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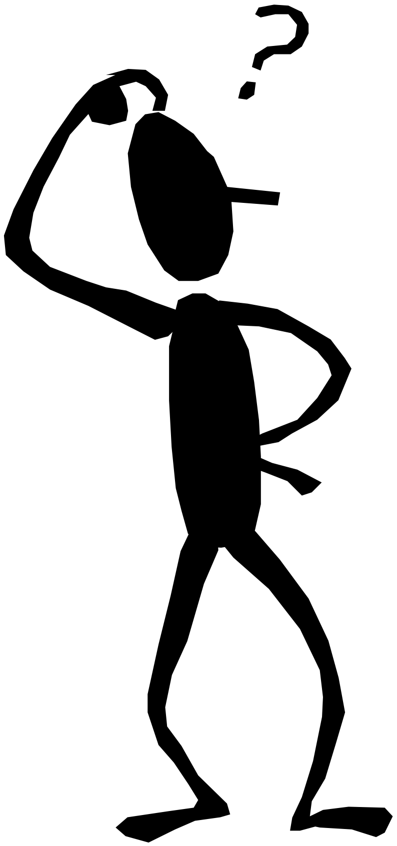
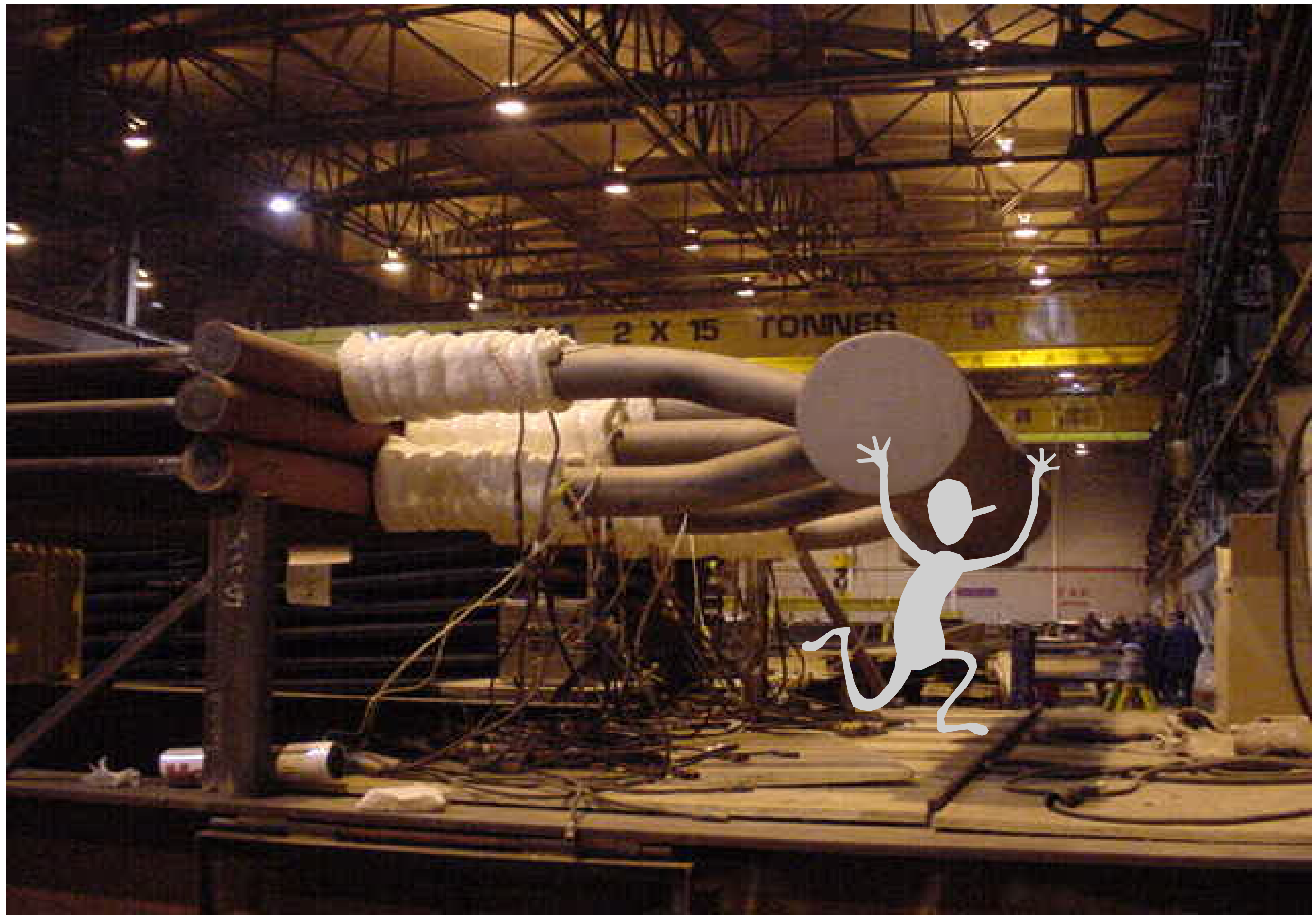
Proper support is always required.





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Agenda

Hardness Presentation Outline

• 1st Topic	Need for Hardness Testing
• 2nd Topic	Precautions During Testing
• 3rd Topic	Portable Devices Evaluated
• 4th Topic	General Testing Procedure
• 5th Topic	Hardness Testing Summary

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Need for Hardness Testing

Difficulties with Grade 91 Components

- Grade 91 steel
  - Very sensitive to processing
  - Detailed fabrication procedures must be developed
  - These procedures must be followed carefully
- If Grade 91 processing sensitivity not recognized
  - Failure of boiler components
  - Possible injury and loss of life
- Hardness testing
  - Can be used to help assure procedures were followed
  - Nominally non-destructive
  - Relatively inexpensive

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Precautions During Testing

Hardness Testing is not Simple

- As with welding, anyone who thinks that hardness testing is simple has not attempted it
- Hardness testing device usage
  - Requires an understanding of operating principles
    - Device limitations
    - Ability to recognize device malfunctions
  - Requires skill
    - Manual dexterity
    - Developed only through practice

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Precautions During Testing

Hardness Testing is not Simple

- Surface preparation
  - Material sampled is very small, testing is very sensitive to surface condition
  - Unrepresentative material must be removed
    - Paint and oxides
    - Decarburized layer

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Precautions During Testing

Hardness Testing is not Simple, (Continued)

- Smoothness
  - Must be in accordance with procedure requirements
  - The lower the testing device load, the smoother the surface must be
  - Some devices use very low loads and surfaces must be almost shiny
- Flatness
  - Testing devices require at least two measurements at each area
  - Test areas must be flat or measurements will be made at varying depths

Portable Devices Evaluated

Few Portable Devices Suitable for Boiler Applications

- Pin Brinell
  - Based on standard Brinell machine principles
  - Simple and robust, no electronics
  - Relatively high load, minimizes surface condition effects
  - Cannot be used on thin sections, fillet welds, or limited access areas
  - Considered best device for general usage
- MIC 10
  - Based on ultrasonic contact impedance principles
  - Relatively low load, significantly influenced by surface condition
  - Must be calibrated using calibration block having same nominal composition, microstructure, and hardness as test area
  - Considered best where Pin Brinell cannot be used

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Portable Devices Evaluated

Few Portable Devices Suitable for Boiler Applications

- Equotip, TIME, and similar devices
  - Based on Shore Schleroscope (indenter rebound) principles
  - Relatively low load, significantly influenced by surface condition
  - Significantly influenced by test area mass and rigidity
  - Cannot be used on thin sections
  - Considered unsuitable for boiler applications
- Computest SC
  - Based on standard Rockwell machine principles
  - Uses very low load, significantly influenced by surface condition
  - Has large footprint, requires that welds be ground flush and limits access
  - Must be held very steady during operation to preclude bad readings and indenter damage
  - Considered unsuitable for boiler applications

Portable Devices Evaluated

Few Portable Devices Suitable for Boiler Applications

- TIV (Through the Indenter Viewing)
  - Based on standard Vickers machine principles
  - Relatively low load, significantly influenced by surface condition
  - Has large footprint, requires that welds be ground flush and limits access
  - Very difficult to hold steady on curved surfaces
  - Considered unsuitable for boiler applications

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General Testing Procedure

Total Effort must be Systematic and Carefully Executed

- Select areas for test
  - Location dependent on component
  - Number dependent on prior performance of vendor or particular issue being addressed
- Rough grind
  - Welds only need to be smoothed to remove solidification ripples and other gross irregularities
  - Base materials usually need 1 to 2 mm of metal removal to assure test areas are below decarburized layers
  - Depth of grinding must be reasonably uniform over an area large enough to accommodate all anticipated hardness indentations
- Final polish
  - Used to smooth, not reshape, test areas
  - Grit size will depend on load of testing device

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General Testing Procedure

Total Effort must be Systematic and Carefully Executed

- Take measurements at each test area
  - Two if using Pin Brinell
    - Maximum and minimum diameters of individual impressions must not differ by more than 0.1 mm
    - Brinell hardness values must not differ by more than 10 HB points at any test area
  - Five if using MIC 10
    - Running average used to evaluate individual test values
    - Individual test values that differ from running average by more than 30 HV points must be discarded

Hardness Testing

Summary

- Hardness testing is not simple
- Testing is important to help assure safety and reliability of boiler components
- Testing must be performed by skilled personnel
- Suitable devices must be used
- Testing procedures must be followed
- For hardness acceptance criteria, see Alstom Standard 2-2004-10

Welding and Hardness Testing Program Summary

Summary and Concluding Statements

Open Discussion

BACK

FIELD WELDING OF TUBES AND PIPES IN GRADE 91
ISSUES AND EXPERIENCES

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Abstract
This paper presents the preparations, field experiences, and essentials to be addressed in order to implement a successful P91 field welding program.

INTRODUCTION:

Welding is an important activity in fabrication of pressure-part components. Most boiler component welding is performed in accordance with the *ASME Boiler and Pressure Vessel Code, Section I*, .Power Boilers,. *Section IX,* .Welding and Brazing Qualifications. Field fabrication poses the following challenges when compared to shop fabrication:

- Location of weld
- Weather conditions
- Control in inventory
- welding process

Field welding and its controls of CEFS(Creep Enhanced Ferritic Steels) material are challenging. The published reports of failures of P 91 grade materials, focuses on field welding abuses in general and improper pre heating and post weld heat treatment (PWHT) in particular. In view of this we would like to share our field experience in this context.

REQUIREMENTS

The following procedures are to be followed prior to commencement of fabrication.

- Welding Consumable procurement and storage procedures
- Welding procedures specification
- Procedure qualification record
- Welder qualification
- Heat treatment procedures
- Inspection and testing procedures

Welding Consumable Specification and Storage: The performance of Grade 91 welds depends having the correct chemical analysis in the weld metal; Filler metals shall be purchased with test reports showing actual chemical analysis for the specific heat/lot and with impact testing. Shield metal arc welding (SMAW) electrodes shall satisfy strict (H4) moisture criteria to avoid hydrogen embrittlement or moisture related phenomena requirement. Crater cracking and other undesirable grain boundary phenomena can be minimized by ordering weld metal with low residual element content- {Bruscato Formula (or "X-Factor"; where, $X = 10P+5Sb+4Sn+As$)} X Factor < 15. Covered electrodes with Mn/S ratio greater than 50 and

Mn + Ni less than 1.5 shall also be indicated in the purchase specifications. For SMAW, the literature says E9015-B9 electrodes are preferred as EXX15 type electrodes have no extra iron powder in the coating like EXX18 electrodes, eliminating one source of contaminant.
Storage and baking of welding consumables shall be carried out in a separate oven. The ovens shall be heated by electrical means and shall have automatic heat controls and visible temperature indication. In order to avoid mix up of electrodes & to ensure proper baking, logs shall be maintained.

Welding procedures specification: WPS are generally prepared in line with ASME Sec IX. WPS shall provide correct guidance to welders. Pre-heat & Interpass shall be emphasized. temperatures. Stringer bead in root welding with slight weaving in filler pass shall be indicated. Thickness of bead shall be restricted to max of 4mm. Purging of inert gas for minimum of two passes or 9.8 mm shall be indicated. Staggering of start stops, grinding of craters at stops shall be carried out. Impact testing for performance qualification record (PQR), PWHT & Post baking requirements shall be clearly specified in the specification.

Procedure qualification record: shall be carried out with impact testing and multiple PWHT to simulate repair welding qualifications.

Welder qualification shall be carried with Radiographic testing & bend test. More emphasis shall be given on welder knowledge, skill and heat input control during qualification.

Inspection & Testing Procedures: Detailed procedure for heat treatment, Inspection & Testing shall be prepared & approved before starting the erection/fabrication activities.

FIELD EXPERIENCE AND SITE REQUIREMENTS

The site Activities basically involves

Identification of pipe spools

This activity is absolutely important to lift the minimum required pipe spools in sequence and placing them in location. Generally all spools required in a certain location along with heating equipment and purging cylinders are lifted creating congestion and limited work place. Location for placing these should be identified and planned before the start of job to avoid congestion around the work place.

Temporary Protection for Welding

Temporary protection for welding shall be completed before the joint fit up stage and protection against rain shall be ensured. Just to narrate an example: while welding of some of the super heater coils were completed by evening and post weld heat treatment was in progress. We had some sudden showers and the polythene covers protecting the welded areas gave way and water seeped in to the weld which resulted in cutting and re-weld of all the joints.

Joint Fit up

The pipes shall be supported by the temporary hangers. Ensure use of lug of 91 materials during the joint fit up. One pipe shall be aligned and fixed with the master level and alignment shall be carried out on the other. The root gap shall be optimized to2- 2.5mm even though the welders have a tendency to have a larger root gap, thereby preventing welders from weaving during root welds. Alignment of tubes is one of the major problems experienced during fit-up. Most of skilled workers resort to improper thermal correction leading to metallurgical degradation of material. This was partially overcome by conducting training classes and introduction of spool pieces.

Pre Heating

Pre heating was carried out even before the thermo couple was welded to pipes. Then mode of preheating for pipe welding was induction method due to which uniform heating over the entire thickness of the pipe was achieved and PWHT could be carried out on completion of welding in a single setup. However for tube welding, resistance method was adopted with a group of four to five tube sets warped for preheating of tubes. A minimum of three thermocouples shall be used on pipes up to 200 mm OD positioned diametrically opposite with a minimum of one on each pipe and one on the weld and four thermo-couples for pipes greater than 200 NB. However for tubes, the problem was on the usage of number of thermo couples on the tubes. After a lot of deliberations, one per group of tubes was suggested. Finally it was decided to use one per tube which was reluctantly accepted.

Purging of argon gas in piping was comparatively easy and could be monitored easily. However purging of gas during tube welding and monitoring the same was difficult due to space constraint, difficult location and schedule of completion. In the end we felt this is to be monitored more closely as on few occasions it was found that improper purging was carried out during welding.

Welding

The process of pipe welding was Tungsten inert gas welding (TIG) for root pass and SMAW for the remaining passes. Welding work was carried out with two welders on opposite sides welding two half's of pipe/tube starting welding from 6'o clock to 12'o clock position. Crater cracks were observed during welding and every stop start location was ground to remove crater before continuing the next weld. Inter-pass temperature control during pipe welding was easier than during tube welding. TIG process was adopted for tube welding; stringer weld was adopted at the root with slight weaving in the subsequent passes. As per requirement, purging was to be carried out for minimum two passes. Care had to be taken in filling up small incomplete weld at the top after removing the purging tube. During tube welding the inter-pass temperature control was necessary and monitored more closely.

Tendency of welder to deposit more weld metal for an early completion was another hurdle and hence exercising control on the weaving and weld bead thickness was a hurdle. In this area success was partial. Another problem, when welding group of tubes was that, the welders were tending to finish the welding on one half of the tube before moving to the other half of the tube which led to distortion of tubes and joint misalignment. So special training was given to welders to complete one root run to the entire tube before starting subsequent passes. In case of interruption during welding, at least one fourth of wall thickness should be completed and preheat shall be maintained until the groove is completed. This poses problem at site as emergency arrangements shall be in position to take care of such contingences.

Post Weld Heat treatment

PWHT is one of the single most important factors in producing satisfactory weldments in P91 materials. Regardless of thickness or diameter preheating and PWHT are mandatory to reduce hardness and to restore ductility in the weld metal and heat-affected zone. One has to seriously monitor the completion of welding, reducing of temperature to 100ºC & immediately start PWHT. This is the most difficult activity. As PWHT needs to be carried out immediately after welding, the bottle neck is queuing of jobs for PWHT . As we all are aware to get satisfactory weldments PWHT immediately after welding is the best. However in case of delay in PWHT post bake out is carried. It varies from manufacturer to manufacture- some have a procedure PWHT shall be carried out within seven(7) days of post baking, others manufacturers have a procedure stating, three days after post baking and in some literature if TIG welding is carried out post backing is not essential. The fabricator uses theses kind of technique to suit the situation. However we are of the opinion that PWHT shall be carried out immediately on completion of welds.

Post weld heat treatment was carried out by induction method for butt welds of pipes & heating pads were adopted for tubes. However, preheat and post weld for shear lugs pipe supports and seal welding of gamma plugs at site was challenging task which was overcome by using heating pads.

If PWHT is not carried out on completion of the weld, bake out process at site is extremely difficult to monitor. A dedicated team shall be appointed only to monitor the welding operation and PWHT

Inspection & testing

All NDT (RT and MPI) examinations were carried out after PWHT. The rate of defect and repair in pipe welding was minimal when compared to tube welding. Most of the defects observed in tube welding were porosity, incomplete fusion in the root and hardness variations. An interesting observation was made that Magnetic Particle Inspection (MPI) immediately after post weld heat treatment had no indications. However, on the same joint MPI carried after 2 days had some indications in the heat affected zone which were ground and retested after 24hours and observed to have no such defects. Hence most of the joints were tested with MPI after 24 hours to ensure defect free weld joint. The most time consuming and difficult task is hardness measurement of weld joints. It was even more difficult to measure hardness in tube joints due to the narrow profile. The most important observation was that good surface finish was absolutely essential for hardness measurement and consistent readings. Initially hardness measurements were made on the tubes and very erratic values obtained were less than 190HB and 240 HB at certain locations in the same weld. Many hardness instruments were tried and ultimately most consistent reading was obtained using GE-MIC hardness measuring equipment.

The last test that was carried out was Positive Metal Identification (PMI) to ensure the right consumables have been used for welding and to check the values of Mn and Ni. Initially we obtained values of Mn +Ni of 1.75- 2.5. Three sample welds were carried out using the same batch of fillers and electrode and checked at the lab. We found in all the three samples the range of Mn+Ni was between 1 and 1.2. The surface preparation for the PMI check is also absolutely essential to get consistent values of chromium and molybdenum. PMI may be used at site to ensure usage of right fillers and the right material.

Conclusion

The key lessons learned can be summarized as below:

- All procedure to be written, reviewed and approved prior to commencement of fabrication
- Planning of material movement and welding activity
- Provision for adequate temporary weather protections
- Availability of backup power
- Ensure no thermal methods or excessive external force are imparted during fitment and alignment
- Tight control over welding process (preheating and PWHT)
- PMI test shall be carried out only to ascertain the right consumables are used
- Hardness test shall be carried out on all weld joints to confirm proper PWHT is carried out.
- NDT testing shall be carried out only after PWHT.

Acknowledgment

The authors would like to thank the management of TATA Consulting Engineers Ltd., for their encouragement and help in preparation of this paper.

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1. EPRI-1012748-Guideline for Welding Creep Strength-Enhanced Ferritic Alloys
2. EPRI-1004516-Performance Review of PT91 Steel
3. The T91/P91 Book, Vallourec & Mannesmann Tubes

Fabrication and Welding of Grade 91
Special precautions to be taken

Ian J. Perrin

February 2011

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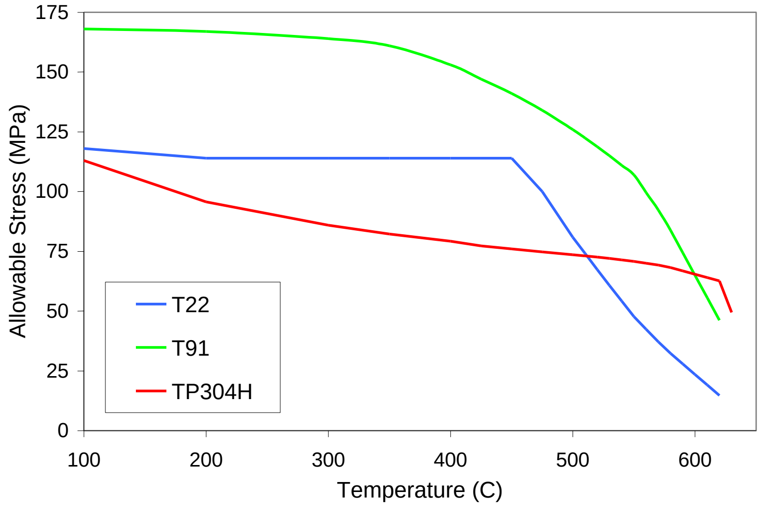
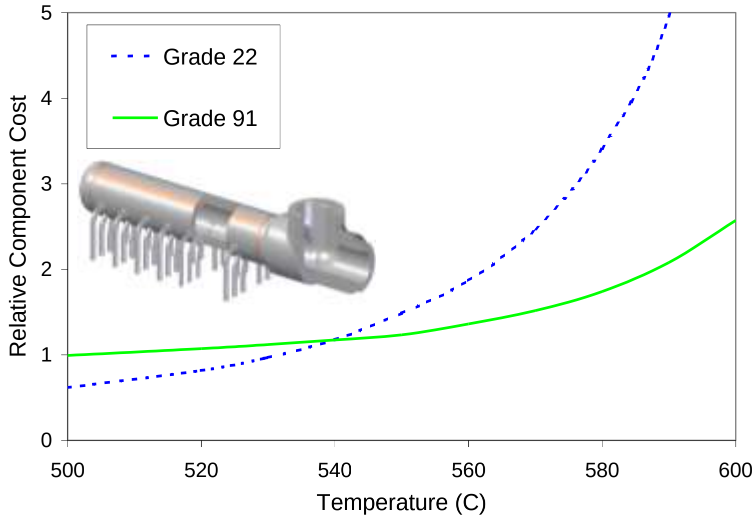
What is Grade 91 Steel?

- Low-alloy steel with 9% Cr, designed for creep strength
  - 9Cr – 1Mo – 0.2V – 0.08Nb – 0.05N (0.1C)
  - Modification of existing 9Cr-1Mo steel (Grade 9)
  - Goal: ferritic steel with strength equivalent to 304 SS
    - Better radiation swelling resistance
    - Lower thermal expansion
    - Better SCC resistance
  - ASME BPV Code qualified Sec I, III, VIII
    - Mid-1980's
    - Tube, Pipe, Plate, Forgings (T91, P91, F91)

Why Grade 91?

- Significant strength advantage compared to Grade 22 (2.25Cr-1Mo)
  - Thinner wall sections
  - Better cycling capability
  - Overall lower cost
    - Base material
    - Manufacturing
- Allows increase in steam temperature and pressure for advanced plants
  - Better thermal efficiency
  - Reduced emissions
- Much improved thermal properties compared to austenitic SS
  - Fatigue resistance in cycled plants





Challenges with Grade 91 Fabrication

- To achieve its excellent creep strength, Grade 91 requires careful control of:
  - Chemical composition
  - Normalizing heat treatment and cooling from normalizing
  - Tempering
  - Post weld heat treatment

- If the material is not properly heat treated within defined limits then the material can become “soft” or “hard”
  - “Soft” Grade 91 has high temperature strength similar to Grade 9
  - “Hard” Grade 91 is brittle and susceptible to cracking

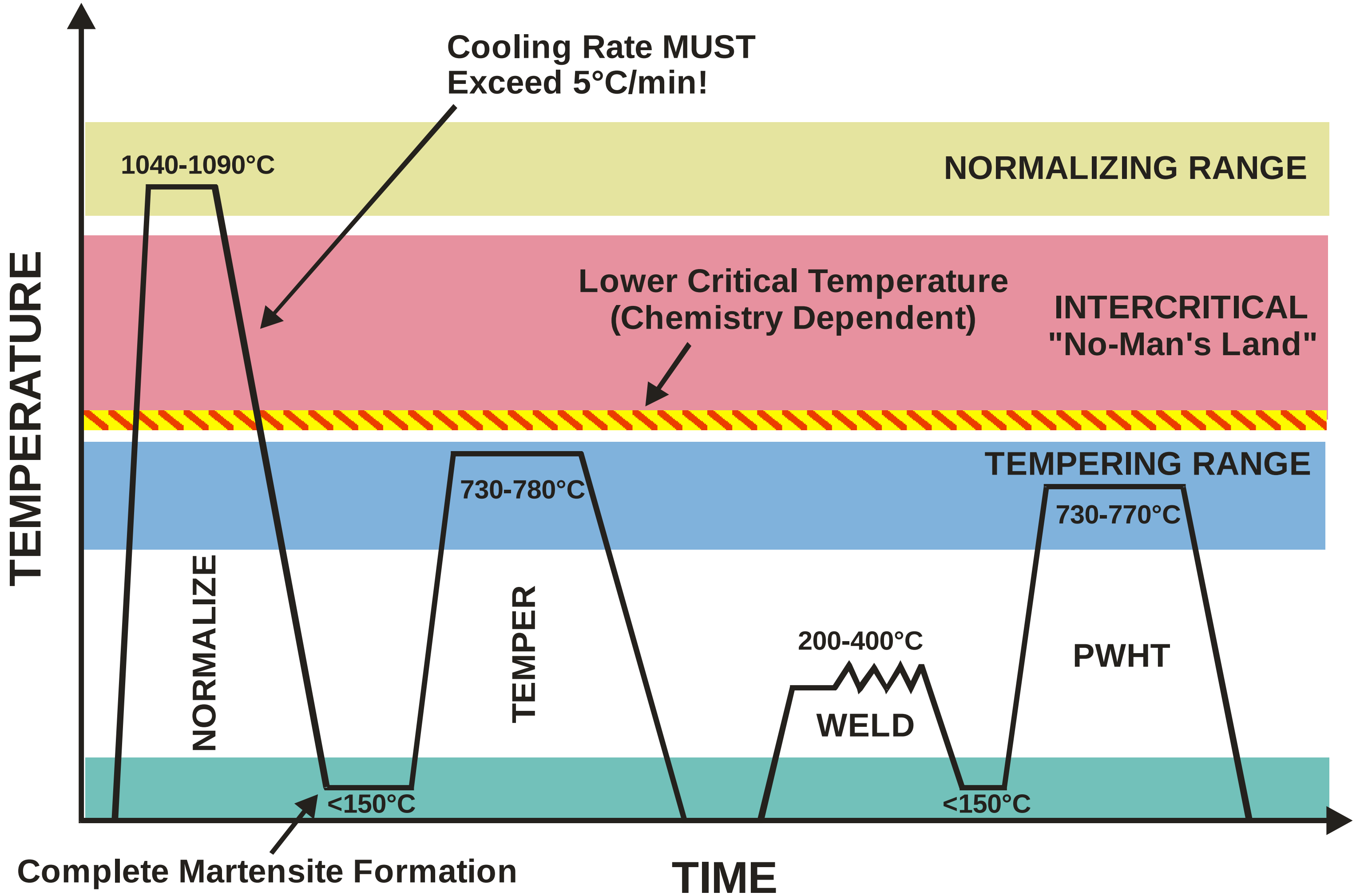
Grade 91 - Chemistry

- Chemistry should be carefully controlled to ensure good, fabricable, material.
  - Ni + Mn has strong influence on lower critical temperature.
    - Higher Ni + Mn benefits toughness
  - Other elements (e.g. Cr and Cu) influence lower critical temperature but to lesser degree.
  - Higher N / Al promotes good creep strength.

- Chemistry controls should be applied to both base material and to weld filler metal.
  - Specific filler metal controls depend somewhat on application, process and consumable.

Grade 91 Heat Treatment

- Careful heat treatment is key to achieving properties…



Potential Heat Treatment Concerns

- When fabricating Grade 91 components, various heat treatments may be needed, if not performed properly they can result in significant serviceability concerns.
  - Improper normalizing
  - Intercritical heating
  - Overtempering
  - Undertempering

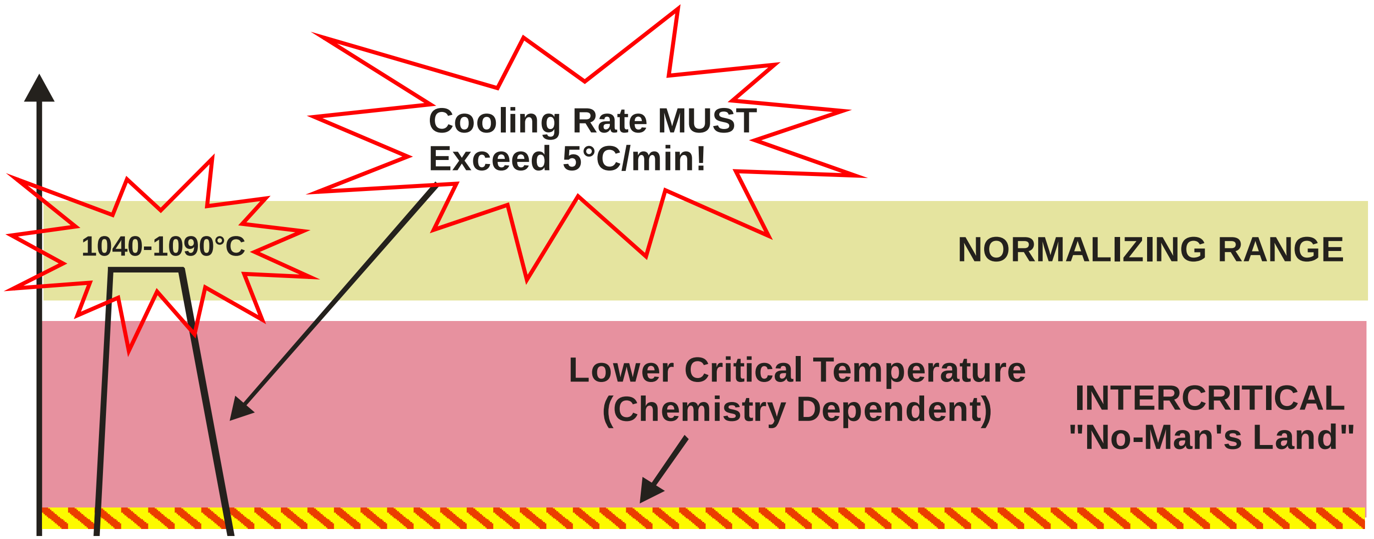
When to Normalize?

- Grade 91 is purchased from the mill in the normalized and tempered condition.

- Normalizing is required in the shop after:
  - Cold / Warm strain levels exceed ~20% (2.5 R/D bends).
  - Hot / Warm working above lower critical temperature.
  - Cold pressing on components designed to operate in the creep range.
  - The post weld heat treatment has exceeded the lower critical temperature.

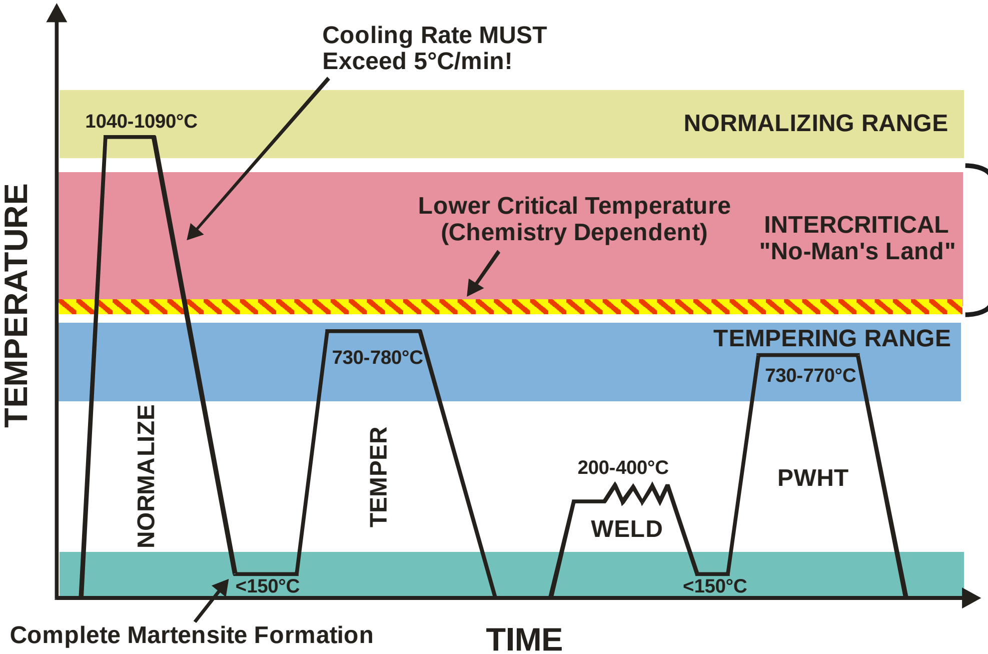
Normalizing – Potential Problems

- Temperatures too low
  - Good Hardness, poor creep strength
- Inadequate time
  - Incomplete solutionization of carbides
- Slow cooling from normalizing
  - Soft ferrite structure
  - Very poor creep strength



Intercritical Heat Treatment

- Some portion of the microstructure will re-austenitize (new martensite forms).
- Precipitates that impart creep strength are not properly formed so the material will have very poor high temperature strength.



Tempering – Potential Problems

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- Heating above A_1
  - Quick cool – increase in hardness
    - Untempered martensite
    - May not detect
  - Slow cool – low hardness (<180 HV)
    - Ferrite structure
  - Poor creep strength in either case
- Overtemper
  - Potential low hardness starting material
  - Multiple PWHT required for complex components
  - Low creep strength if hardness too low
- Furnace uniformity, control very important
  - More than one T/C required!
- Many cases of soft Grade 91 reported

\upt ur ed 91 heat ed above $_1$

Undertempering

- Temperatures below the specified minimum for tempering will result in undertempering.
- The hardness will not be reduced sufficiently increasing risk of brittle fracture and stress corrosion cracking.
- The creep strength of the material will not be fully developed.

Temperatures are insufficient

Grade 91 Local Heat Treatment

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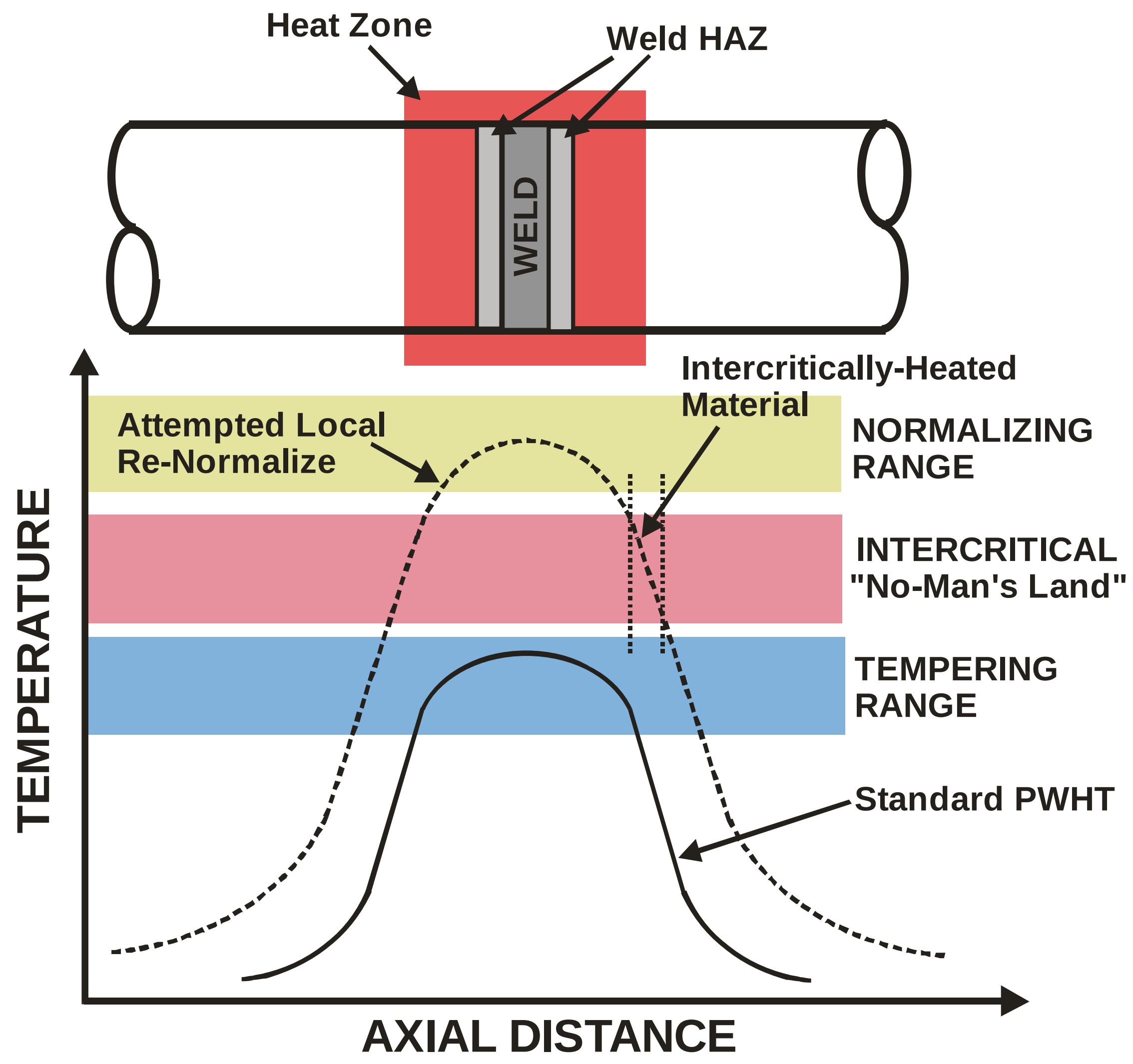
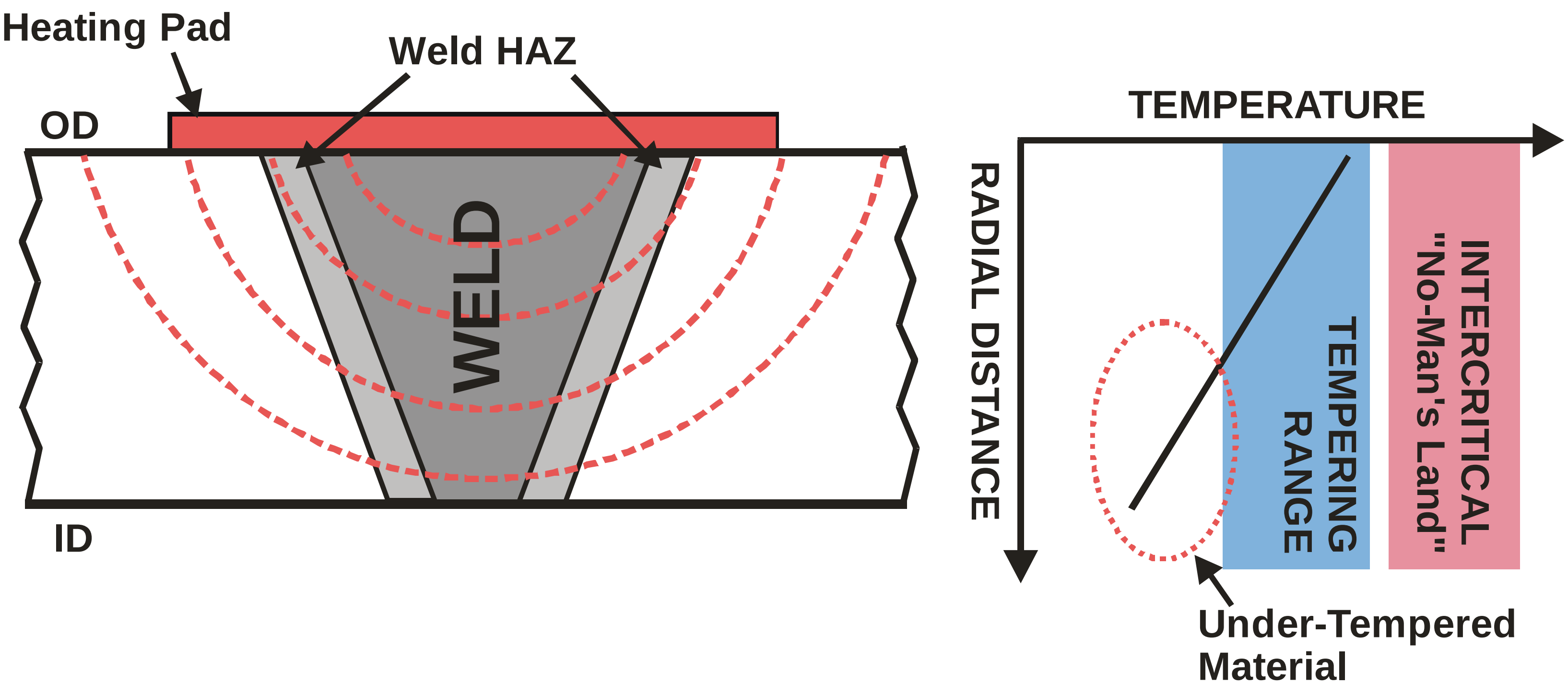
- HAZ and base metal near weld must reach tempering range
- But intercritical range must be avoided
- Local normalizing not possible



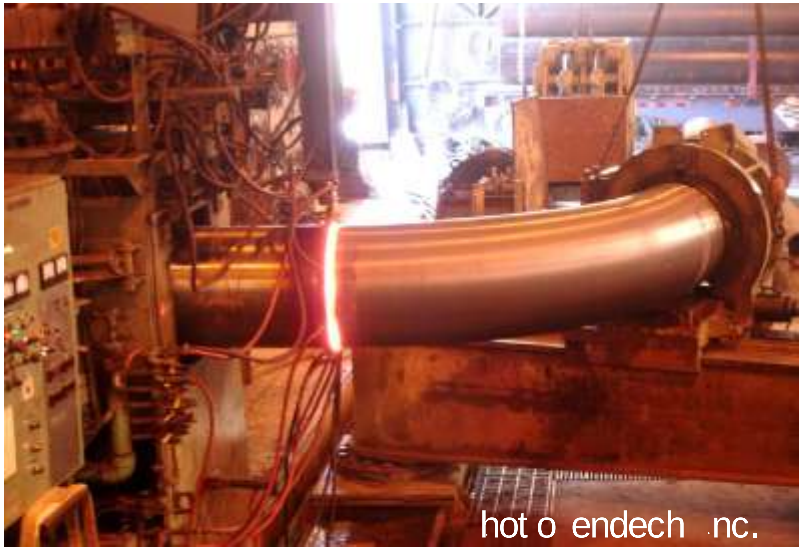
Grade 91 Local Heat Treatment



- Entire thickness of pipe must reach tempering range

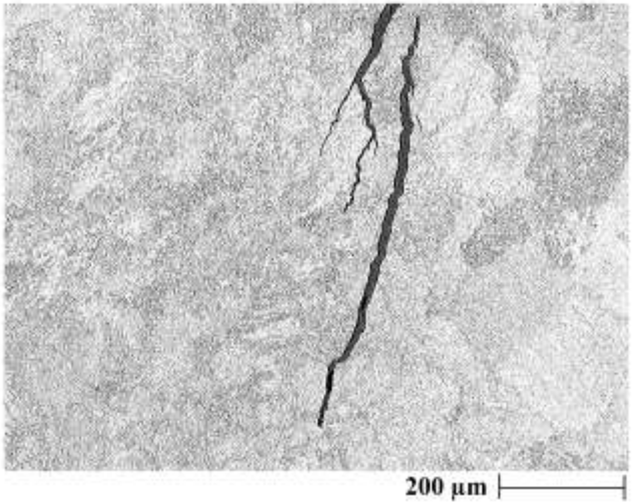
Processing Requirements – Forming

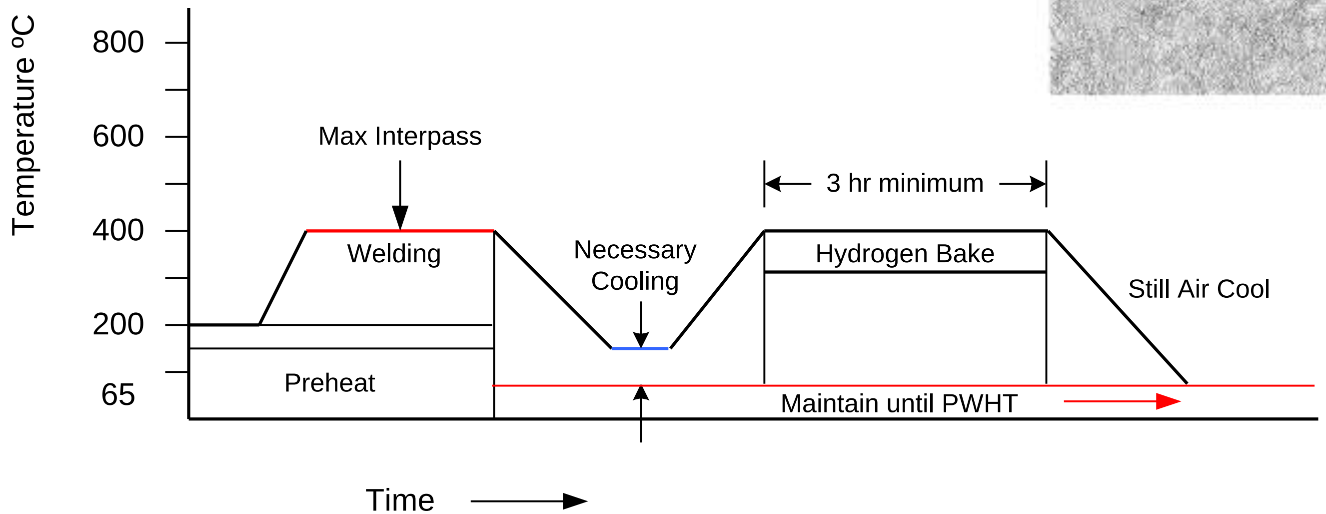
- All hot forming operations MUST be followed by a full N&T heat treatment
  - Otherwise poor creep strength
- “Warm” forming permitted
  - Example: hot adjustments
  - Extreme care needed to not exceed A_1
  - Limited strains
- Cold pressing, swaging must be followed by N&T if material is used in the creep regime
  - Uncontrolled, reversed strains
- Strain limits on cold bending of tubes
  - Strains > 20% require post-bend N&T



Hydrogen Induced Cold Cracking

- Three contributors to Cold Cracking
  - Hydrogen
    - Proper electrode and flux storage is important
    - Preheat & Hydrogen Bake
  - Susceptible Microstructure
    - In the normalized or as-welded condition
  - Tensile Stress
    - Residual stresses from welding
    - Weld joint design
    - External forces





Stress-Corrosion Cracking

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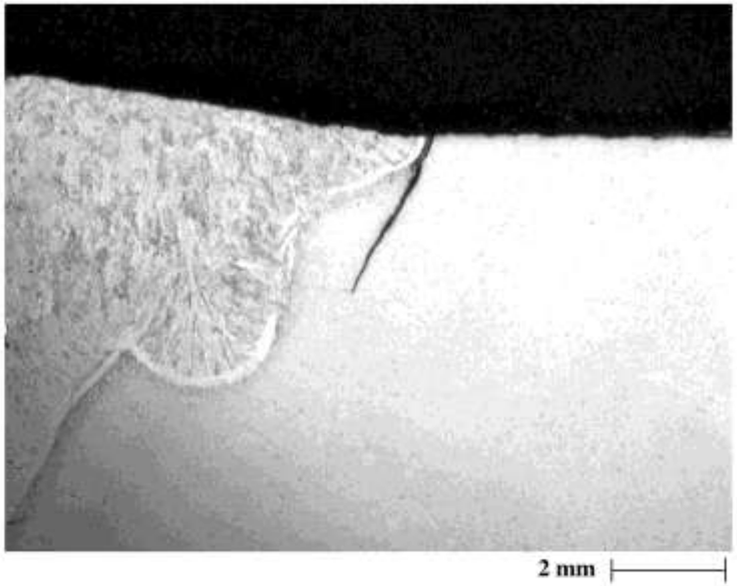
- Untempered or as-welded Grade 91 steel is susceptible to stress corrosion cracking.
  - Susceptible microstructure
  - High local tensile stress
  - Aggressive environmental agent
- Material must be “kept dry” until the postweld heat treatment is performed.



Temperature Measurement and Control

- It is important that all heat treatment furnaces and equipment are accurately calibrated and controlled.
- Temperature variability within a furnace and heating and cooling rates must be understood to know if the furnace is even suitable for heat treatment of Grade 91.
- The temperature requirements must be met throughout a furnace, not just at a couple of thermocouple locations.
- Parts must be adequately instrumented during heat treatments. Thermocouples should be attached to the parts, not just in the furnace atmosphere.
- Similarly, local PWHTs, either in the shop or field, must be properly performed with adequate instrumentation and heating capability.

Processing Requirements – Welding

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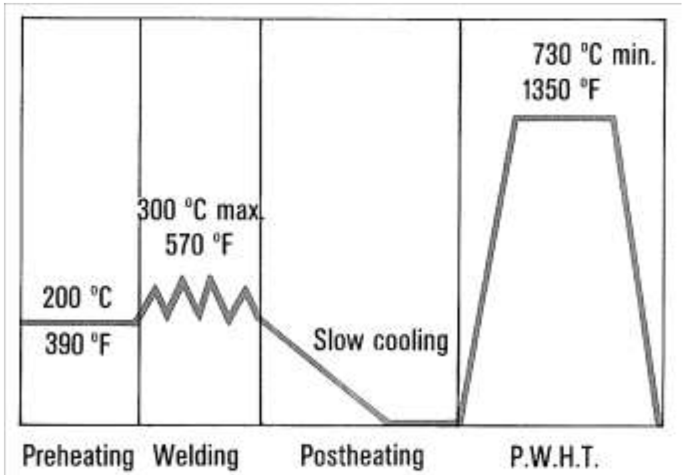
- Grade 91 readily weldable, but requires care.
- Preheat of 200°C required
  - Avoid hydrogen cracking
- Maximum interpass temp of 400°C
- Weld must be cooled to at least 150°C to form martensite, then…
- Immediate post-weld bake or PWHT
  - Bake at 315 to 400°C, 3 hr minimum, to prevent cold cracking
  - Bake doesn't prevent SCC
- PWHT at 730-770°C
  - Tempers martensite in weld metal, HAZ
- Important not to exceed A_1 in PWHT!
  - A_1 for weld filler may be less than base metal

hot o uper heat



Closing Comments

- Grade 91 and other CSEF steels (e.g., Grade 92, 23) offer an attractive combination of properties for design of boiler components.

- CSEF will continue to be used in today's and future plants.
  - Finishing and intermediate SH / RH sections (91 and 92)

- Grade 91, and other CSEF, offer excellent performance if properly handled
  - They are much more sensitive to processing (particularly heat treatment) than more conventional boiler materials – additional care and monitoring needed.

- Communication of guidelines and best practice will continue:
  - Base and weld metal requirements (composition, strength, etc.)
  - Manufacturing specifications
  - Shop training programs
    - Emphasize importance of welding and heat treatment

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Performance of Grade 91 Weldments

Ian J. Perrin

February 2011

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Introduction

- To ensure good performance Grade 91 material the fabrication steps must be performed carefully and conform to all specified requirements (particularly temperature controls).

- Weldment will be a region of potential weakness even in properly fabricated Grade 91 material.
  - The heat affected zone represents a region of weakness

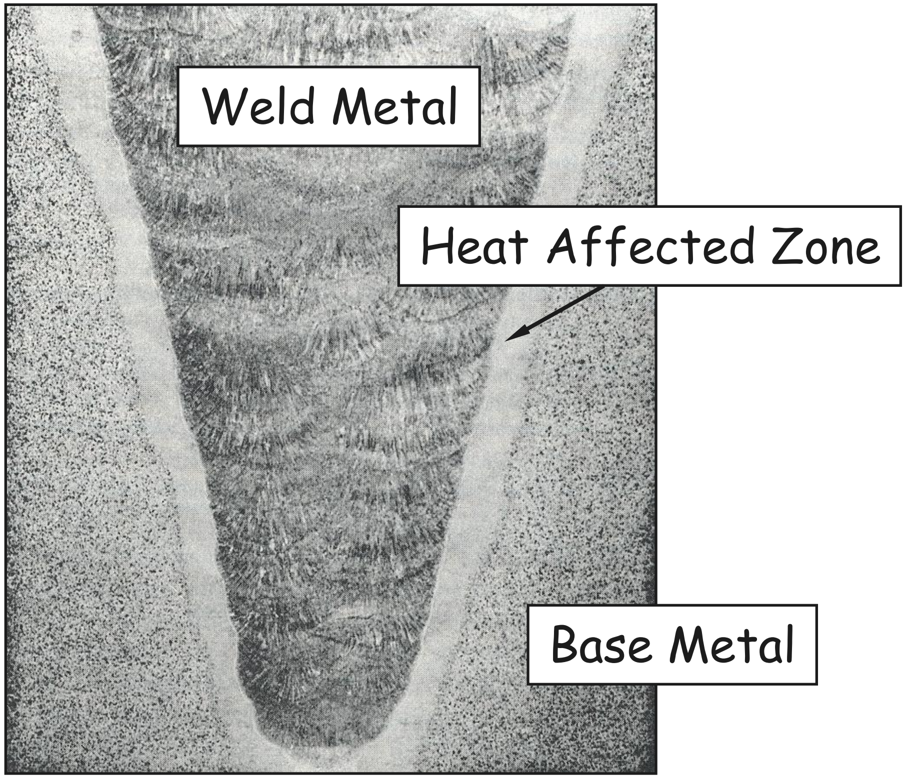
- To understand the influence on serviceability
  - Understand the metallurgy of the heat affected zone
  - Understand the effect of different stresses on weldments

Serviceability of Weldments

- Weldments can preferentially accumulate creep damage due to:
  - Local creep strength mismatch / weak weld zones.
  - Stress concentrations introduced by weld geometry.

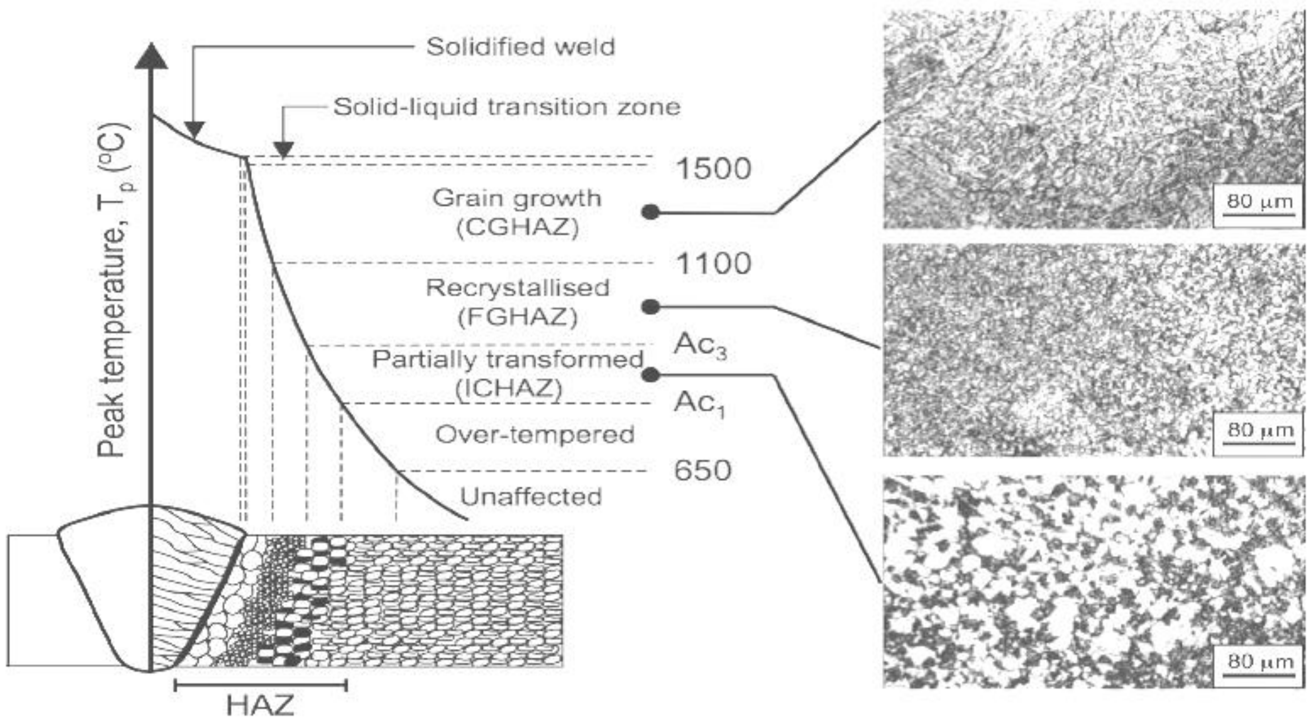
Weld metal can exhibit considerable variability due to weld technique, heat input, etc. Local inhomogeneity can lead to local cracking.

Most cracks are associated with the heat affected zone which can be divided into a number of regions:
- Coarse grained HAZ
- Fine grained HAZ
- Intercritical HAZ



Weldment Heat Affected Zone

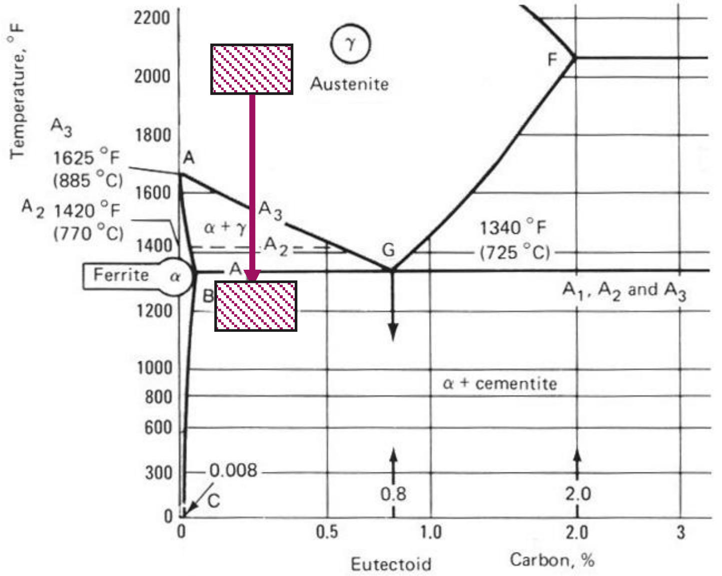
- The heat affected zone (HAZ) is the region of base metal that was not melted but which was "affected" by the heat of the welding process.
- Because Grade 91 material is sensitive to heat treatment, the heat affected zone is especially important.

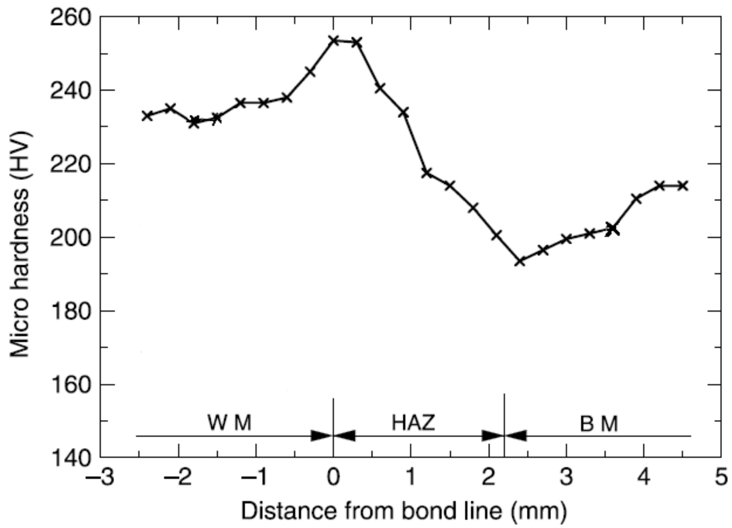


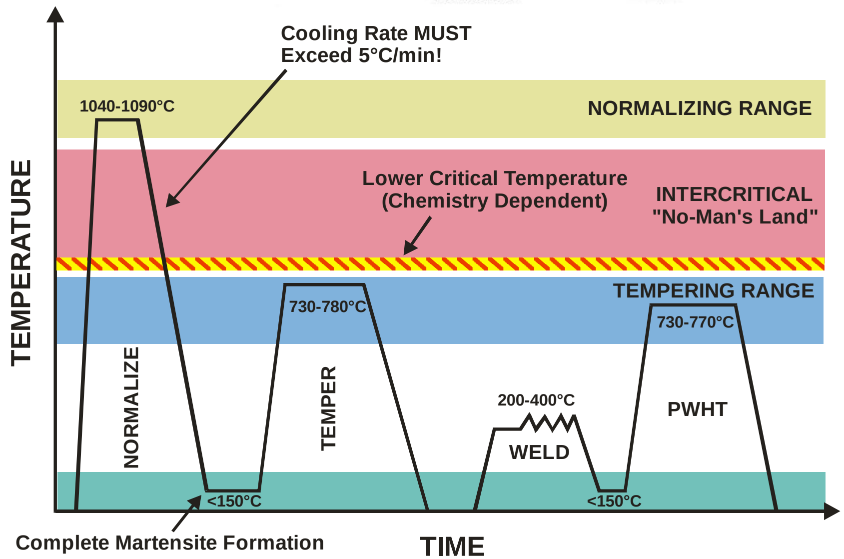
Grade 91 Weldments – HAZ

- To achieve good performance, Grade 91 must be carefully normalized and tempered.

- However…
  - Different regions of the HAZ experience quite different heat treatments resulting in a range of microstructures with different strengths.







Strength Reduction at Low Hardness

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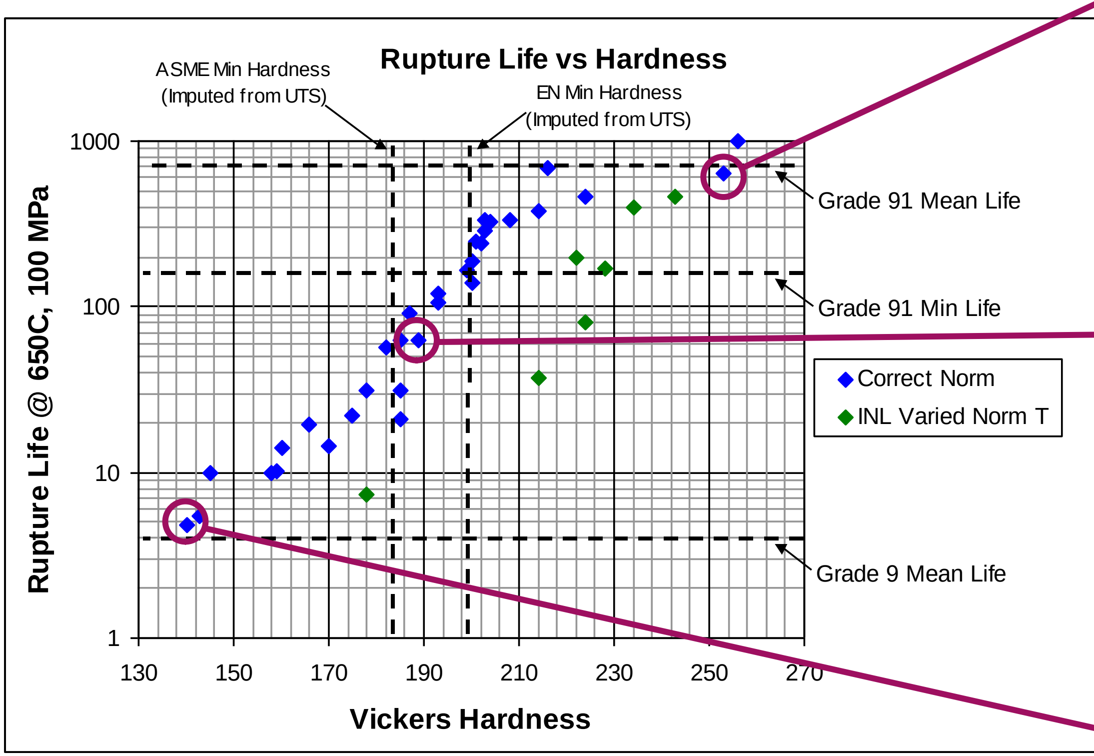
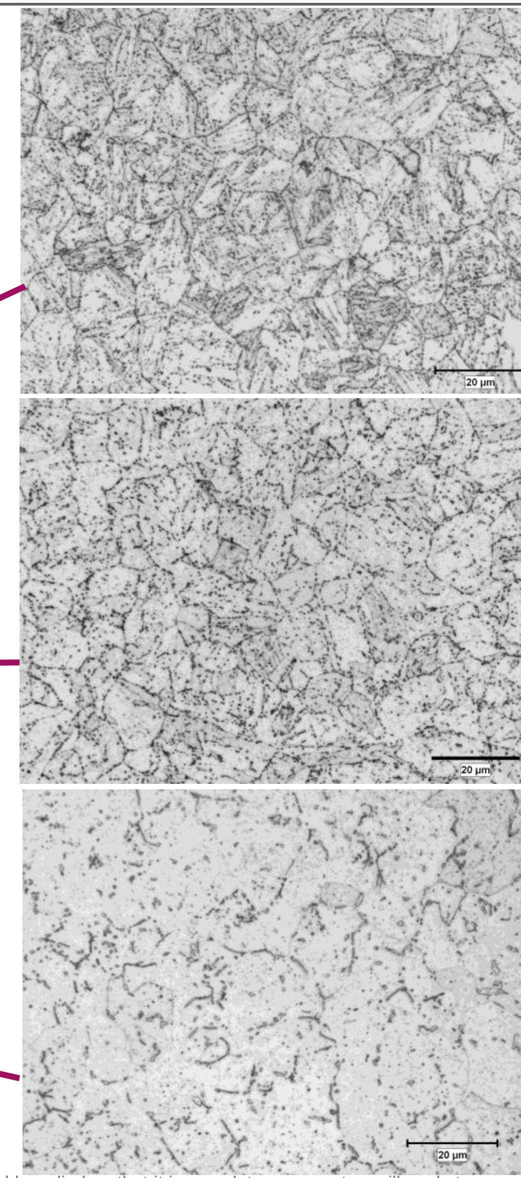
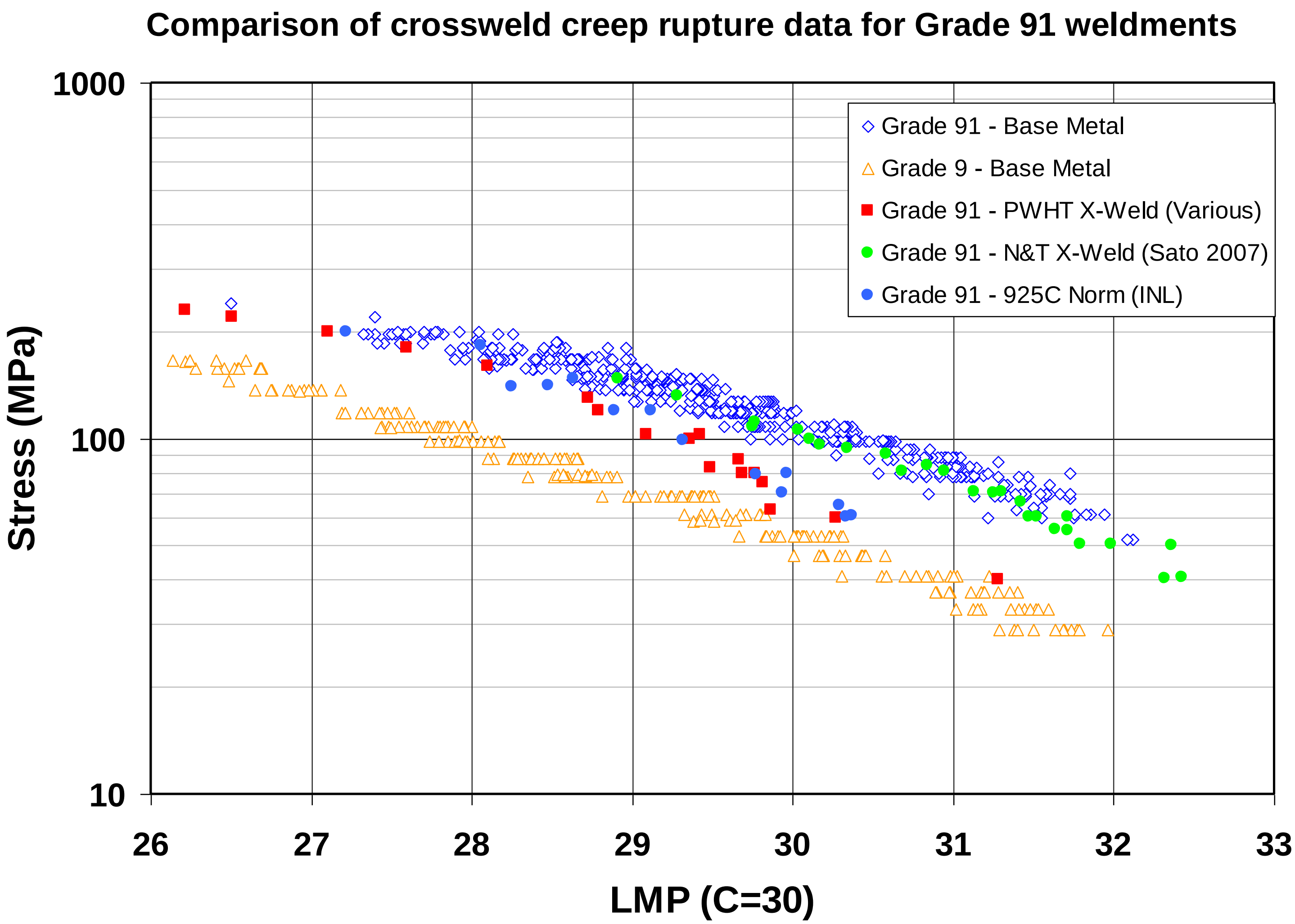
Heat input from welding → Range temperatures from near melting to below lower critical → Range of different microstructures → Range of different strength (hardness)



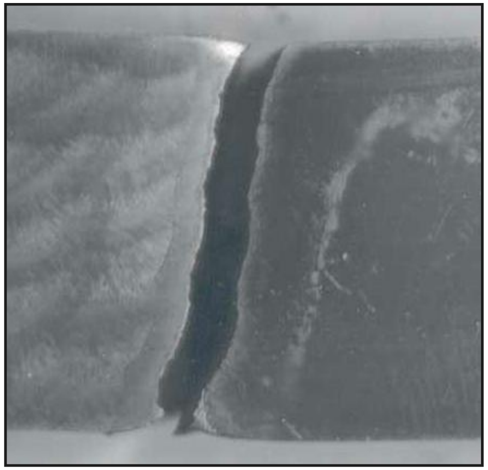


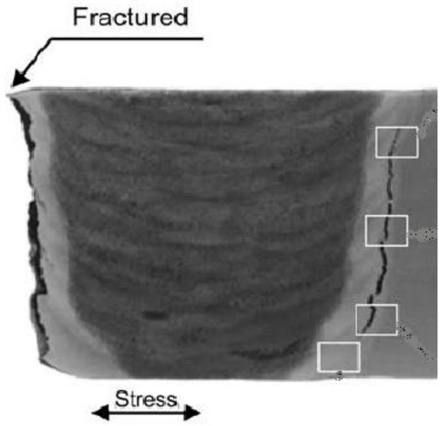
Strength Reduction Due to Type IV Cracking



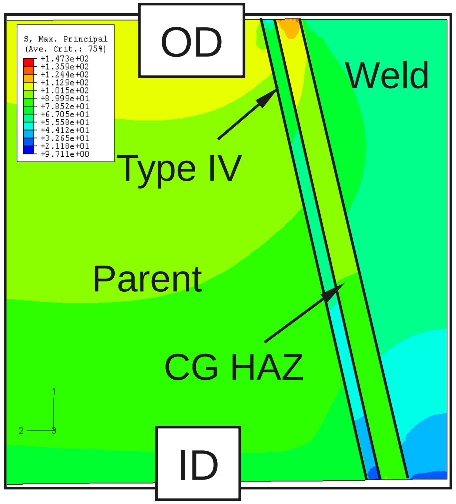
Type IV Cracking Characteristics

- Cracking (due to extensive creep damage) occurs in the partially transformed parent metal (intercritical HAZ). This region has low creep strength due to fine grain size and over-aged precipitates.
- Creep damage occurs relatively uniformly through wall but is often not evident at the surface.
- Once the creep cavities begin to link, crack growth occurs rapidly through the heavily creep damaged material.





(Watanabe et al., IJPVP, 2006)



Type IV Cracking Characteristics

ALSTOM

- Metallurgical effects result in the formation of the type IV zone, whether cracking is experienced depends significantly on loading imposed on the weld.

- Predominantly internal pressure loading
  - The weaker type IV zone is constrained by the stronger surrounding material.
  - Type IV damage is not likely, or requires very long times (in-excess of normal service life) to occur.

- Predominantly axial loading
  - The weaker type IV zone is directly stressed by the applied load and the weakness of the zone is revealed.

- Largest concern is with headers and piping that may be subject to system loads (axial and bending stress).

Dissimilar Metal Welds – 1

- Dissimilar metal welds (DMWs) are created when two different materials are joined.
  - e.g. Grade 91 to a stainless steel (TP347H).
- Such welds are made with nickel alloy fillers.
  - High strength.
  - Intermediate thermal expansion coefficient.
- A heat affected zone is again created in the Grade 91 material.
- Weakness can be further exacerbated by carbon migration from Grade 91 to nickel filler metal.

Dissimilar Metal Welds – 2

- Carbon migration can also occur when Grade 91 is welded to lower alloy steels such as Grade 22.
  - The higher chromium grade 91 can cause local decarburization and weakening of the grade 22.
- Care must be taken in selecting heat treatment conditions for mixed metallurgy weldments.
  - Generally follow Grade 91 requirements, but some cases may warrant modified rules.
- To avoid problems with dissimilar welds:
  - Locate welds in regions with low axial / bending stress.
  - Avoid exposure to high service temperatures.
  - Minimize stress concentrations at thickness transitions.

Some Reported Weldment Service Issues

- Premature failure of P91 weld due to improper post weld heat treatment
  - Cause:
    - Excessive softening caused low creep rupture strength of weld and base material.
  - Mitigation:
    - Replace affected material and re-weld following correct procedures.

- Type IV cracking of end caps, header nipples and pipe butt welds
  - Cause:
    - Geometry / loading exposed weakness of type IV zone.
    - Some cases exacerbated by material condition (low N:Al ratio).
  - Mitigation:
    - Modify geometry to reduce stress concentration.
    - Modify loading (e.g. pipe supports) to reduce stress.
    - Replace material.

Some Reported Weldment Service Issues

ALSTOM

- Cracks at dissimilar metal welds to flow meters
  - Cause:
    - Geometry and cyclic thermal stresses due to expansion mismatch caused local fatigue cracks.
  - Mitigation:
    - Modify geometry to decrease stress concentration.
    - Replace flow meter with alternate material.

Summary

- Grade 91 weldments have an inherently weak zone within the Heat Affected Zone.
- This region can be susceptible to “Type IV” cracking if the “cross-weld” stresses are greater than the “hoop” stress.
  - Axial or bending stresses expose the weak zone.
- Dissimilar metal welds to Grade 91 material also cause a weak heat affected zone, but introduce added complications of carbon migration and thermal expansion mismatches.
  - Minimize thickness transitions or other stress concentrations and locate in regions of low “cross-weld” stress
- Grade 91 weldments can provide good service if these facts are recognized during design and if fabrication follows the requirements for Grade 91 (particularly heat treatment).

www.alstom.com

BACK

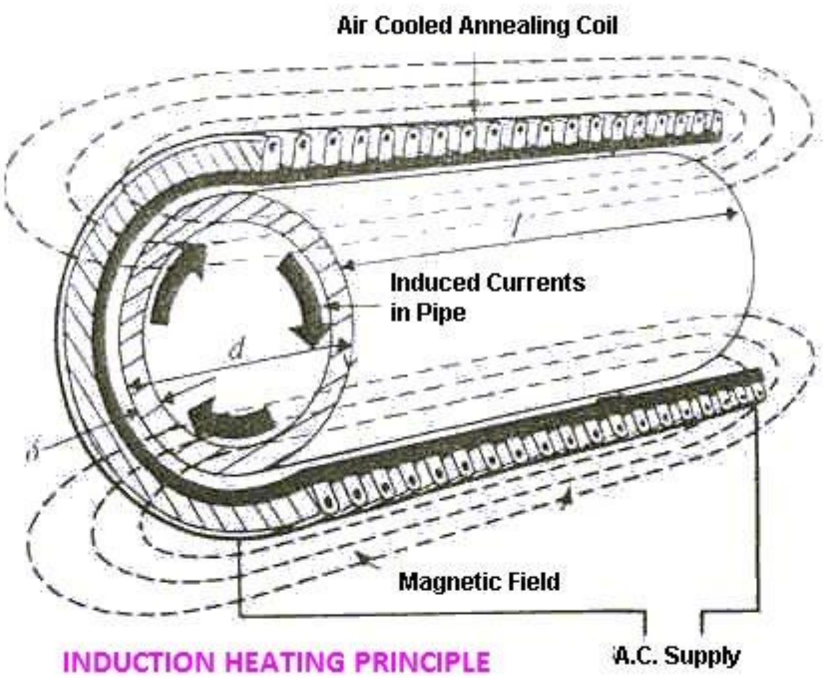
POWER

NEW GENERATION COMPACT INDUCTION HEATING EQUIPMENT

NEW GEN COMPACT INDUCTION HEATING EQUIPMENT

Induction Heating Equipment is used for heat treatment of special alloy pipes like X20, P22 and P91 during welding and post weld heat treatment in thermal power plant main steam piping.

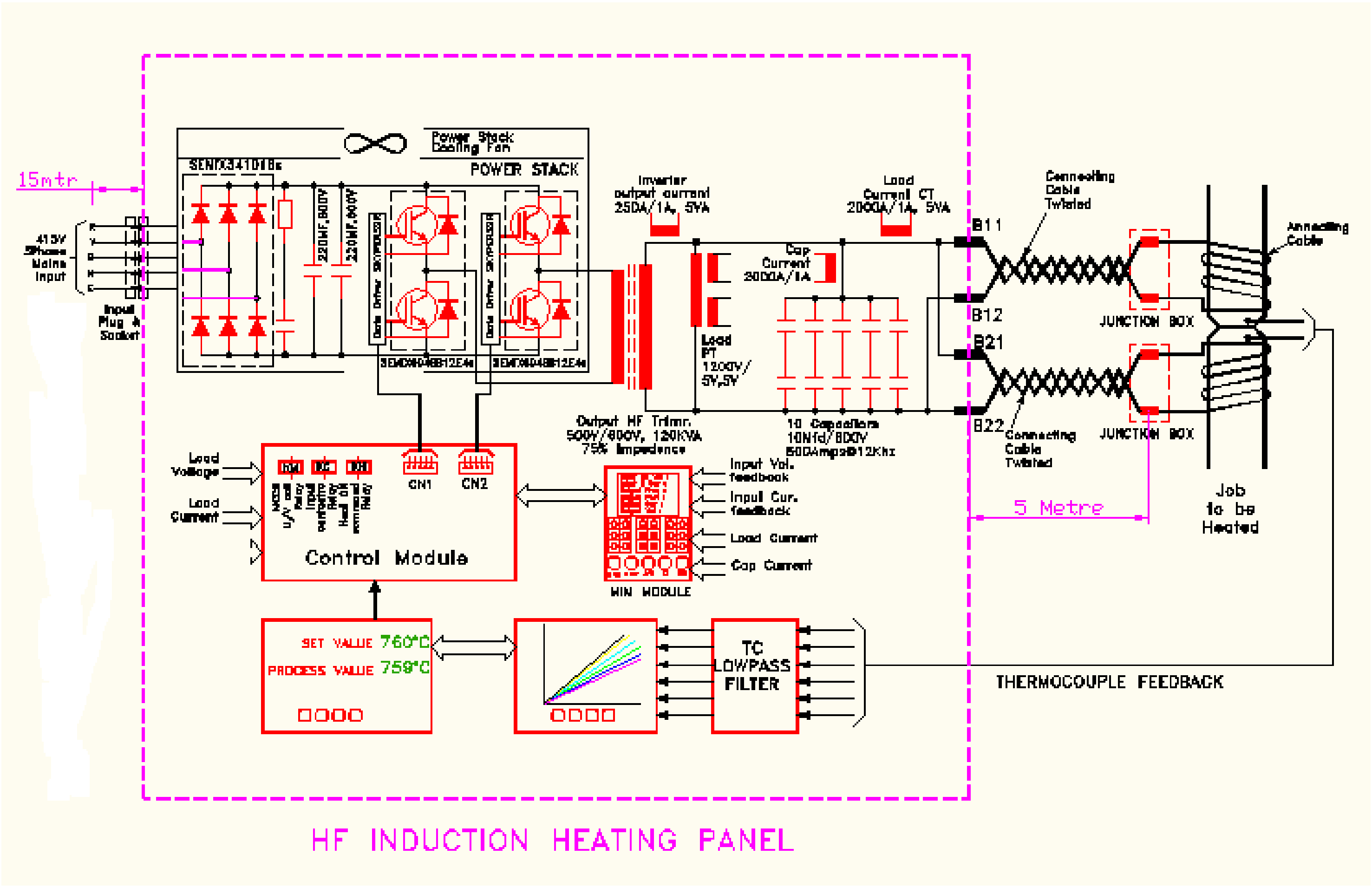
INDUCTION HEATING PRINCIPLE



COMPACT INDUCTION HEATING EUIPMENT SPECIFICATION

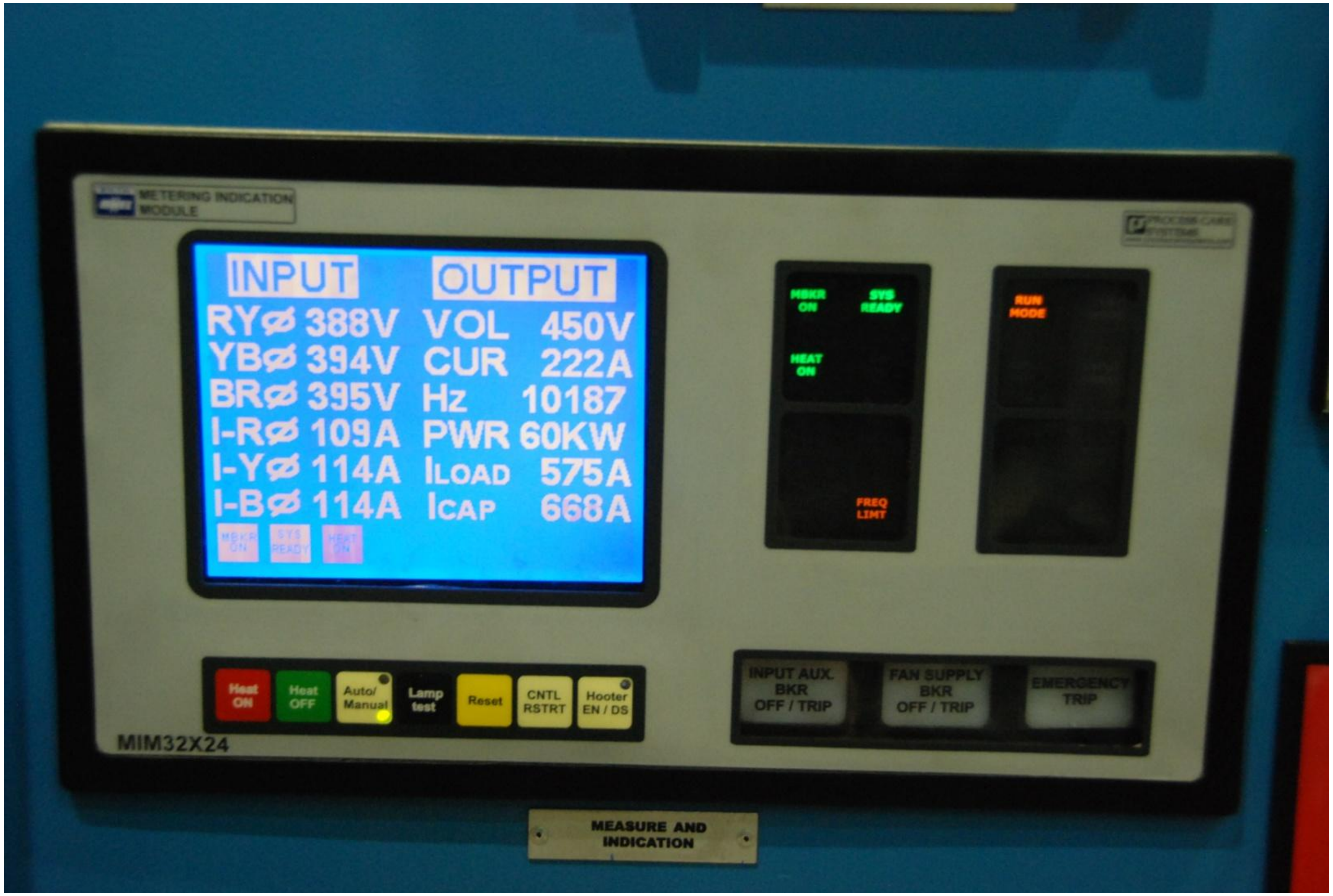
POWER RATING	: 75KW
INPUT SUPPLY	: 415VAC, 3 PHASE, 50HZ
INPUT FEEDER RATING	: 130Amps.
OUTPUT FREQUENCY	: 7500 to 10000HZ
LOAD VOLTAGE	: 130V to 800V
LOAD CURRENT	: 900Amps (max.)
COOLING	: FORCED AIR
ANNEALING CABLE	: NATURAL AIR COOLED
JOB DISTANCE FROM PANEL	: UPTO 5Mtrs.
PANEL SIZE (in mm)	: 950(w)x1250(D)x1500(H)
WEIGHT OF PANEL	: 285Kgs.

SCHEMATIC OF COMPACT INDUCTION HEATING EQUIPMENT



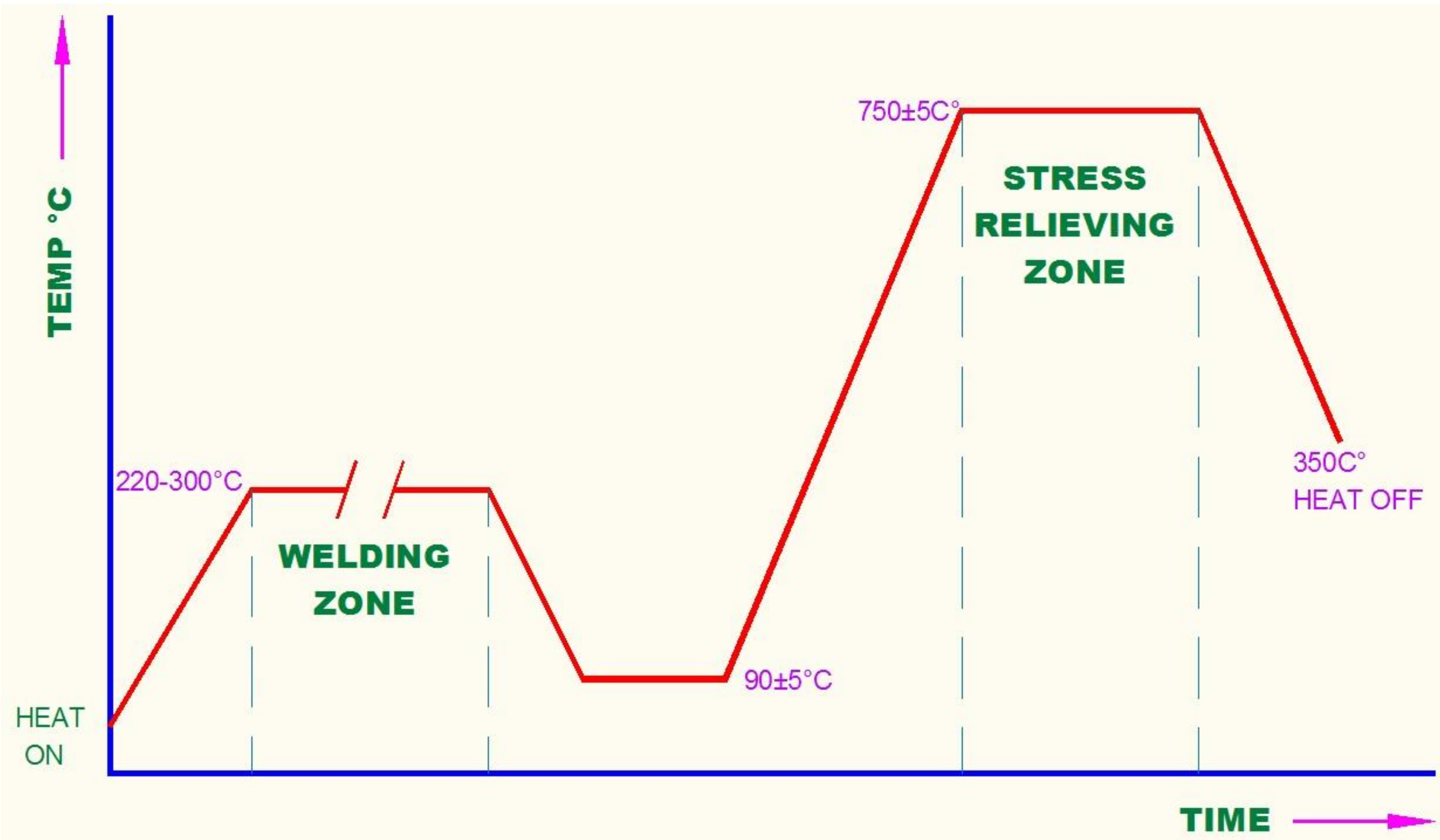
COMPACT INDUCTION HEATING PANEL

COMPACT INDUCTION HEATING METERING, CONTROL & DISPLAY MODULE

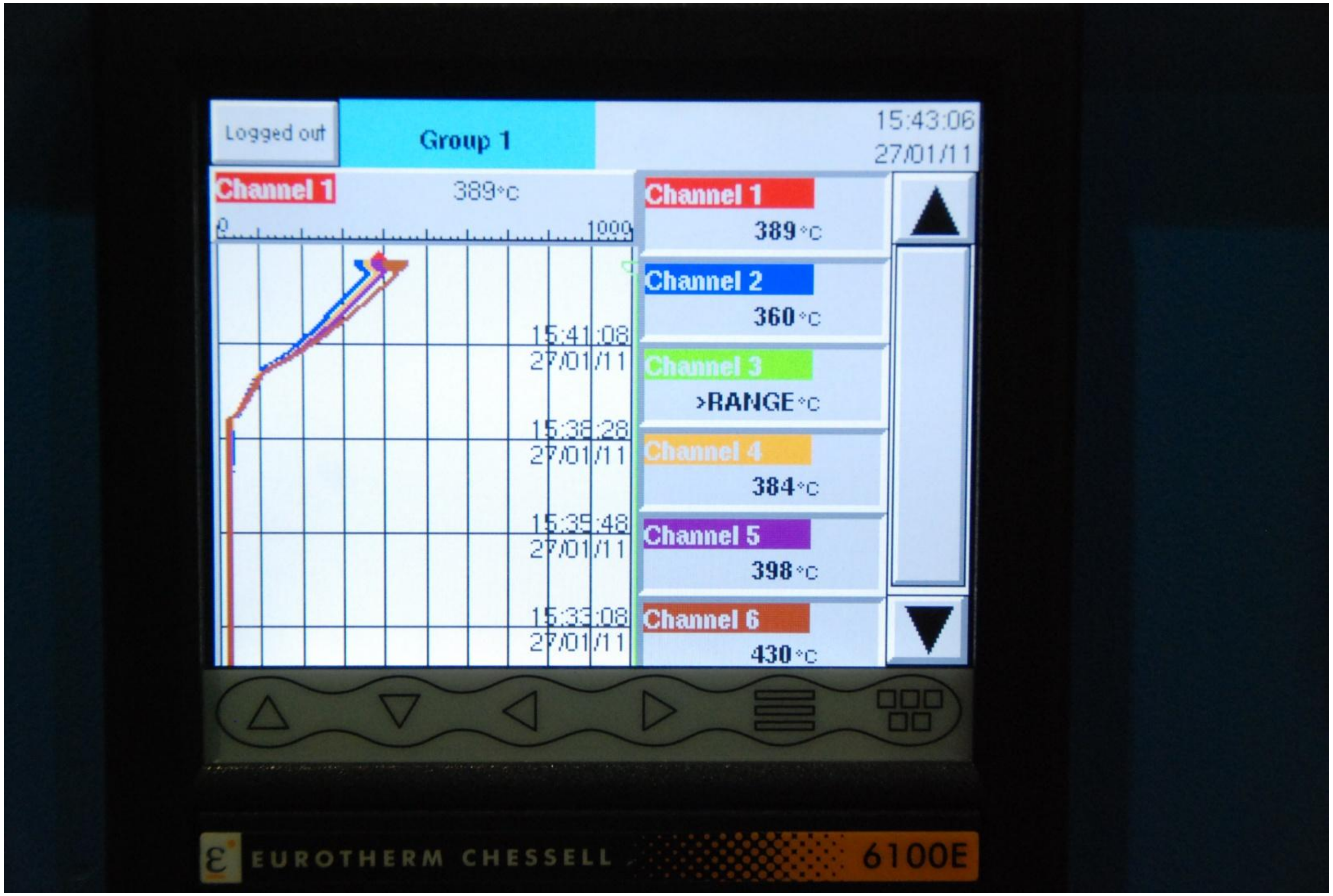


COMPACT INDUCTION HEATING PID CONTROLLER

TYPICAL P91 HEAT CYCLE



COMPACT INDUCTION HEATING TEMPERATURE RECORDER

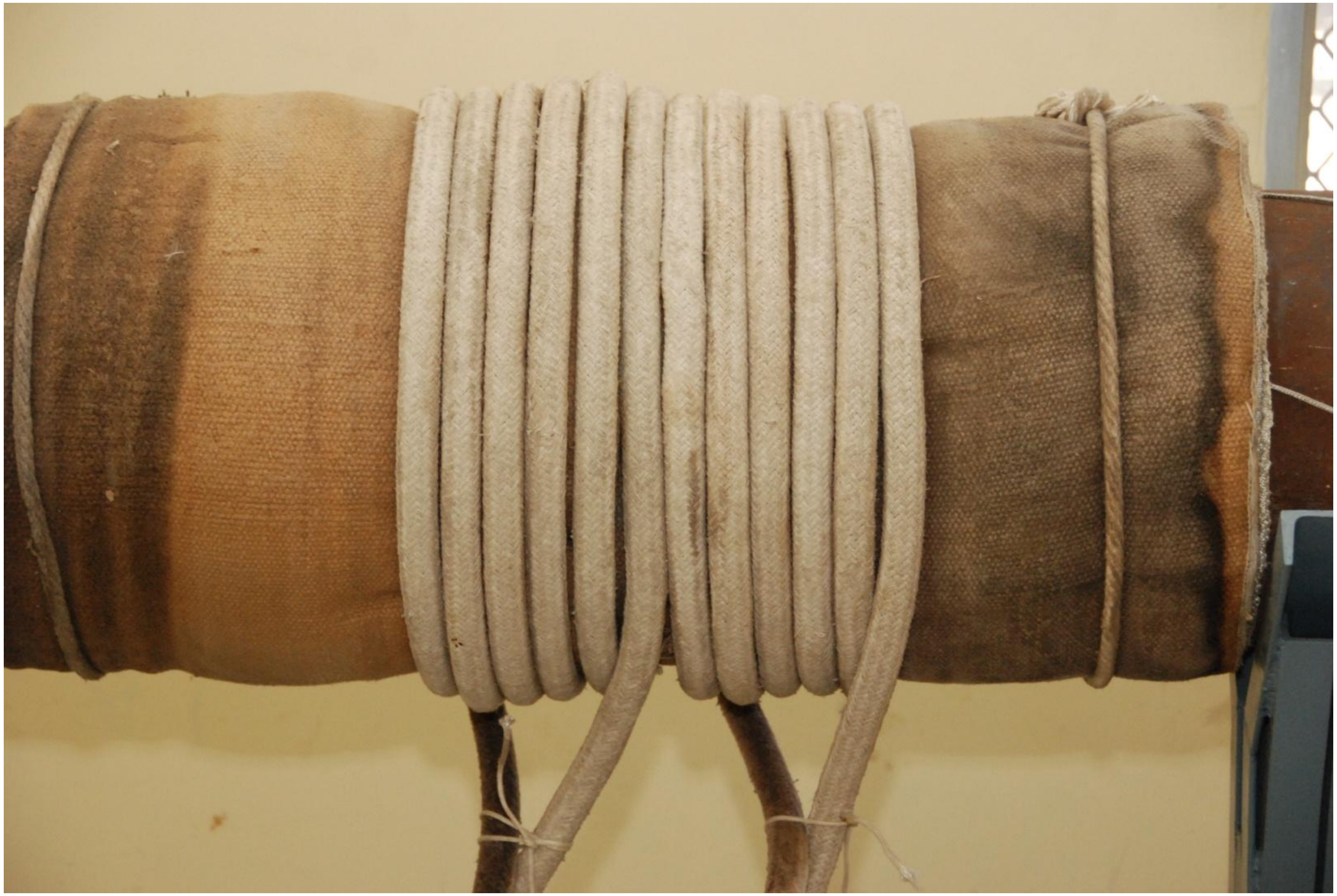


INSTRUMENTS PANEL OF COMPACT INDUCTION HEATING EQUIPMENT

JOB PREPARATION FOR HEATING

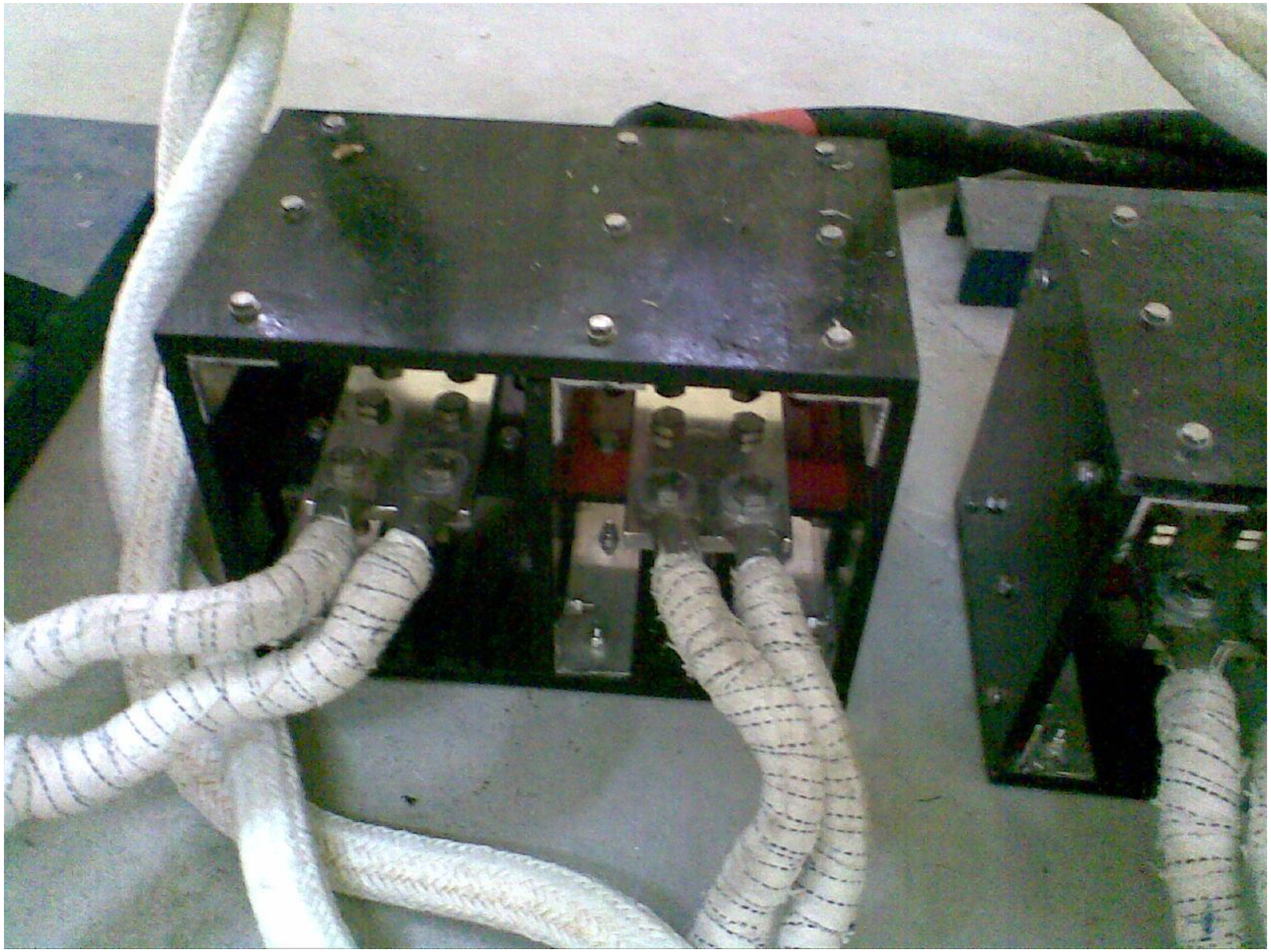
WINDING OF PWHT INSULATION

WINDING OF ANNEALING CABLE OVER INSULATION

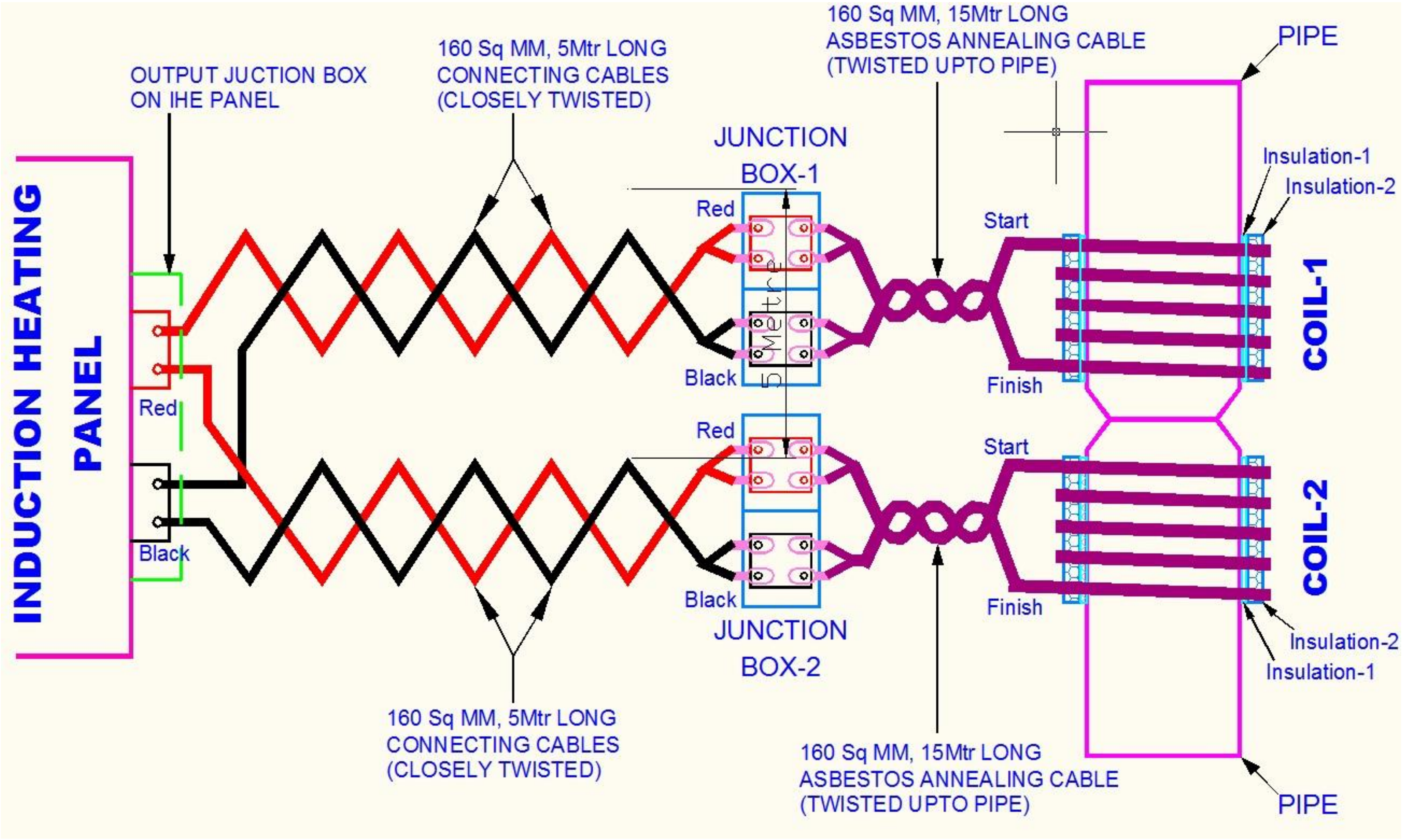


HEATED PIPE USING
NEW GEN COMPACT INDUCTION HEATING

TERMINATION OF ANNEALING CABLE AT JUNCTION BOX



INTERCONNECTION BETWEEN PANEL & JUNCTION BOX



TURNS TABLE FOR JOB HEATING

Sl No.	Pipe Size Dia. x Thickness in MM	Coil - 1 No. of Turns	COIL-2 No. of Turns	Insulation Thickness in MM
01	238 x 29	9	9	25
02	282 x 47	8	8	25
03	311 x 31	7	7	25
04	355 x 22	6	6	25
05	400 x 22	6	6	25
06	430 x 42	6	6	25
07	458 x 46	5	5	25
08	490 x 80	5	5	25
09	516 x 85	5	5	25
10	565 x 62	5	5	25
11	579 x 56	4	4	25
12	791 x 62	3	3	25

SALIENT FEATURES OF
COMPACT INDUCTION HEATING EUIPMENT

- EASY HANDLING DUE TO COMPACT SIZE & LESSER WEIGHT.
- PANEL PROVIDED WITH WHEELS.
- POWER CIRCUIT IS WITH HIGH PERFORMANCE IGBTs.
- DEDICATED PID PROGRAMMER FOR EASY PROGRAMMING AND FINE CONTROL.
- ALARM IN RAMP, DWELL DURING PROGRAM CYCLE.
- PAPERLESS DIGITAL TEMPERATURE RECORDER WITH INBUILT MEMORY FOR RECORDING UPTO 30 DAYS.
- BATTERY BACK-UP FOR TEMP. RECORDER AND TIME TOTALISER, TO RECORD JOB TEMP DURING POWER FAILURE.
- COMPLETE PANEL IS AIR COOLED.
- ANNEALING CABLE IS NATURAL AIR COOLED.
- EQUIPMENT SUPPLIED WITH REQUIRED ACCESSORIES.

BACK

NDE OF P91 MATERIALS

R.J.Pardikar
AGM /NDTL
BHEL,Tiruchirappalli-14

NDE during Manufacturing

NDE

Qualitative

(Conventional techniques)

Quantitative

(Advanced techniques)

Quality through NDE during Manufacturing

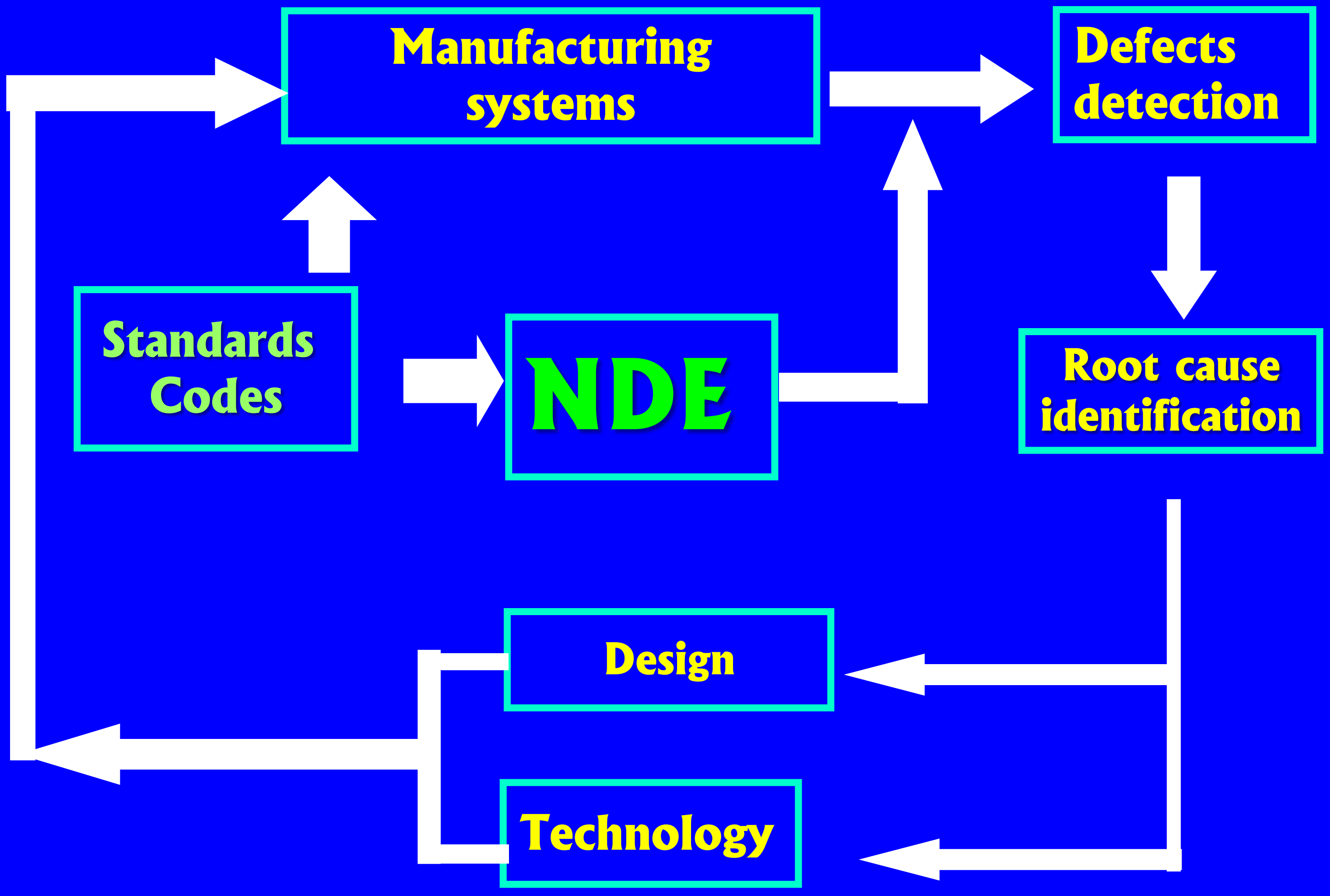
Present Practice

- ✍ Inspection
- ✍ Defect detection
- ✍ Defect sizing & Characterization

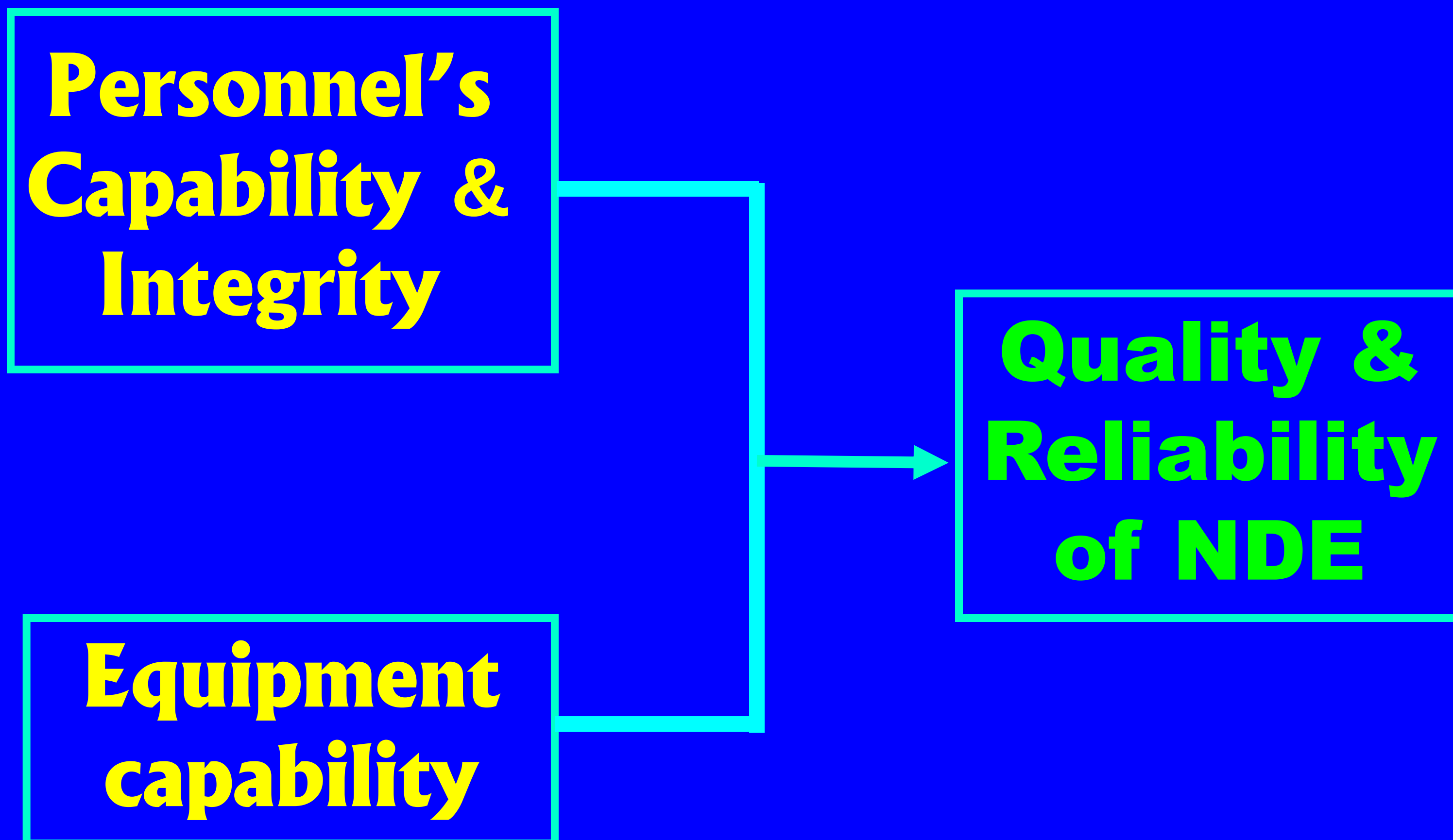
Shift in NDE Philosophy

Defect prevention by root cause identification & process correction rather than Defect detection

NDE Feed back system



NDE Reliability



Why P91?

Of all the materials used for high-temperature steam piping and headers ,P91 stands out because of following benefits :

- High creep rupture properties even at elevated temperatures
- Greater strength, that permits increased safety margins in existing units.
- Significantly longer component life under given creep and fatigue duty.
- Reduced wall thickness for piping for the same design conditions, leading to lower thermal storage and less thermal stress.

Applications of P91 at BHEL

Manufacturing of:

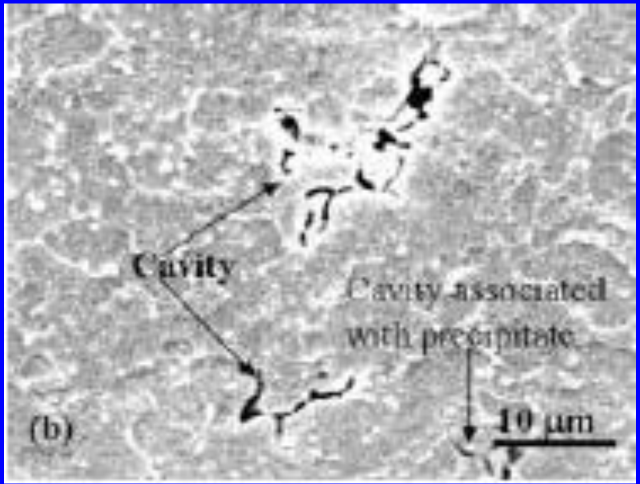
- **Main steam pipe line**
- **Re-heater headers**
- **Tubular Products**

P91-Metallurgical Pitfalls

- Difficult to Fabricate and Repair.
- P91- Superior mechanical properties depend on martensititc transformation plus precipitation of secondary carbides
- Needs careful control of an intricate heat treatment / tempering regime.
- Any action that alters the heat treated micro structure will quickly degrade alloy's properties.
- P 91 susceptible to Type IV cracking – occurs in the fine-grain section on the base-metal side of the heat-affected zone of a weldment.
- Some of the tight quality control steps to ensure defect free fabrication, lengthen the production schedule and increase cost.

P91-Metallurgical Pitfalls

Type IV Failure in Weld joint



Type IV cavity in Inter critical region of HAZ

P91-Major steps during fabrication

- Controlled cooling of the component to below 100 Deg C -To ensure the complete transformation of the steel to a martensitic microstructure.
- Nondestructive evaluation (NDE) for both the surface and subsurface of the weld and surrounding base material- LPI, MPI,UT and RT.
- Post-weld heat treatment (PWHT) - tempers the material (increases the ductility and toughness), and eliminates the risk of stress-corrosion cracking – Done at 760 Deg C for about two hours - Temperature during PWHT shall not exceed the lower critical transformation (AC1) temperature - Otherwise creep-rupture properties will be adversely affected.

P91-Major steps during fabrication

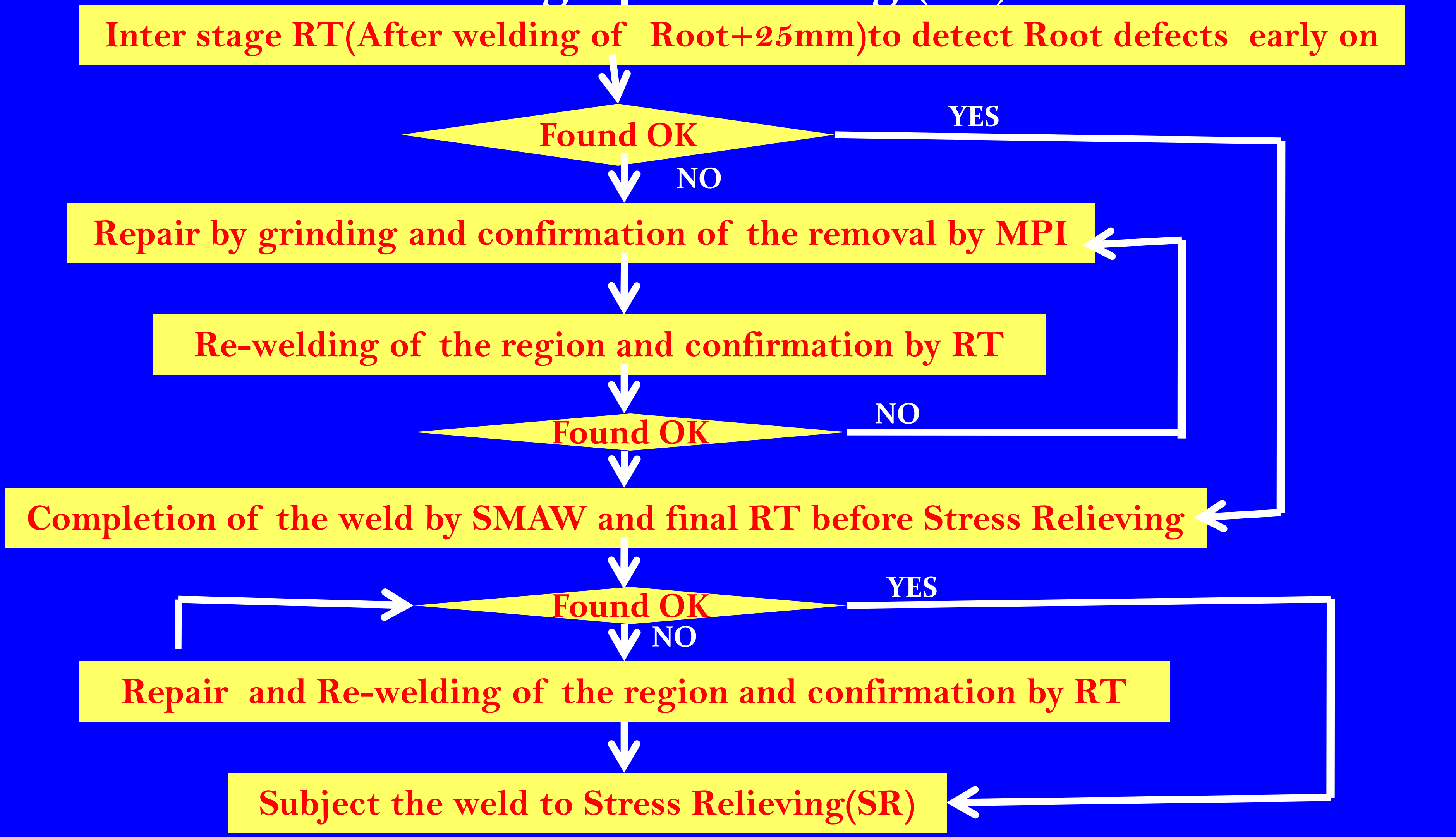
- Proper selection of filler materials
- A preheat phase at approximately 220 Deg C - Non uniform heat distribution results in deterioration of Mechanical properties
- A closely controlled inter pass phase 350 Deg C max.

Fully fabricated P91 Header

Non Destructive Evaluation (NDE) of P91 welds in Pipes and Headers

BUTT WELDS:100% RT,100% UT, and 100%MPI

Radiographic Testing (RT)



NDE of welds in Pipes and Headers

Ultrasonic Testing (UT)

- UT After SR, using Longitudinal and Angle beam Pulse Echo Technique
- Methodology & Acceptance –As per AD Merkblatt HP 5/3 and ASME Sec V/ VIII
- Detection of longitudinal defects by Axial Scanning
- Detection of transverse defects by Circumferential scanning.
- Scanning to be done on either side of the weld from OD Surface with at least two angles (45 & 60 degrees) probes.
- Reference blocks fabricated from the same material, with same dimension and thickness as weld, with Side Drilled Holes and Notches as reference flaws.
- Evaluation-No crack, Lack of Fusion, In Complete Penetration (irrespective of Size)Acceptable .Acceptance of Slag, Porosity as per HP 5/3, ASME Sec VIII

NDE of welds in Pipes and Headers

Ultrasonic Testing (UT)

Normal beam scanning of header butt welds

Angle beam scanning of Header Butt welds

NDE of welds in Pipes and Headers

Magnetic Particle Inspection(MPI)

Inter Stage MPI:

- For detection of defects in Root Pass
- Hot MPI using Yoke and special magnetic powders
- Alternatively in the cool condition -Coil Method

MPI After SR:

- For detection of surface and slightly sub-surface defects
- Wet Fluorescent Continuous method using Yoke
- Wet fluorescent MPI preferred over Dry method to detect cracks with high sensitivity
- Prod method prohibited to avoid arc strikes
- Evaluation under Black light

NDE of welds in Pipes and Headers

Magnetic Particle Inspection(MPI)

Inter Stage MPI using Coil method

NDE of welds in Pipes and Headers

Magnetic Particle Inspection(MPI)

Root Crack detected by Inter stage MPI using Coil Method

NDE of welds in Pipes and Headers

Magnetic Particle Inspection(MPI)

Wet Fluorescent MPI with Yoke for butt weld after SR

NDE of attachments in pipes and Header stub welds

Magnetic Particle Inspection(MPI)

MPI After SR:

- Detection of cracks, lack of fusion in the fillet welds
- Wet Fluorescent Continuous method using Yoke
- Wet fluorescent MPI preferred over Dry method to have good sensitivity of defect detection
- Evaluation under Black light
- Prod method prohibited to avoid arc strikes

NDE of End Cover Plate Weld

Visual Testing (VT)

Inter stage VT: Root Inspection using Video Boroscope.

Magnetic Particle Inspection(MPI)

Inter Stage MPI:

- For detection of defects in Root Pass.
- Yoke used as Prod method may result in Arc strike.

MPI After SR:

- For detection of Surface and Sub surface defects.
- Wet Fluorescent Continuous method using Yoke.

Ultrasonic Testing (UT)

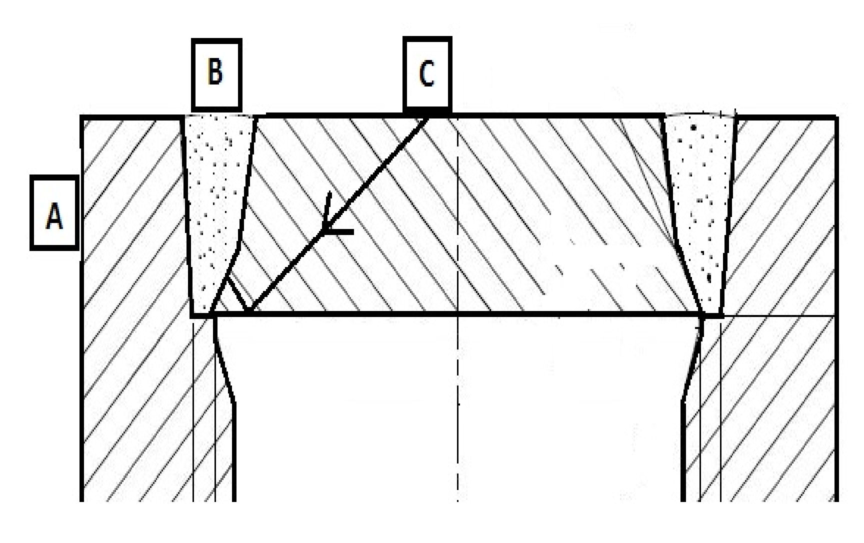
UT After SR:

- Detection of Planar defects at the Root and other fusion zones.
- Normal beam testing from Pipe side as well as end cover side.
- Angle beam examination (45 degrees) from End cover side.
- Evaluation-No crack, Lack of Fusion, Incomplete Penetration (irrespective of Size)Acceptable .Acceptance of Slag, Porosity as per HP 5/3 / ASME Sc VIII

NDE of welds in Pipes and Headers

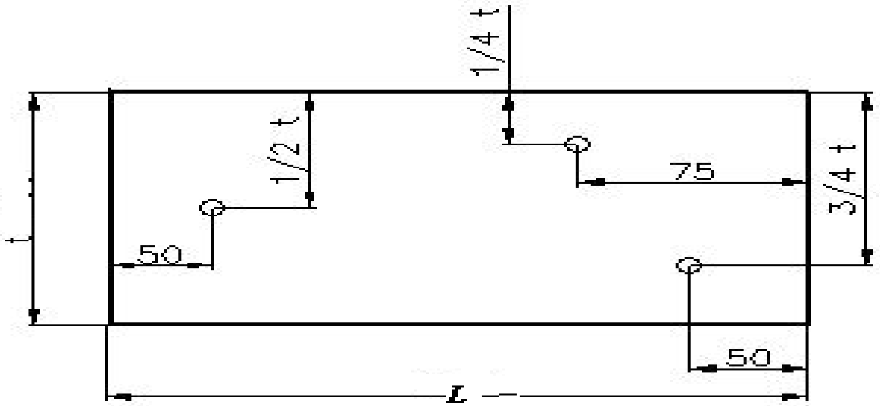
Ultrasonic Testing (UT) of Flat End cover weld

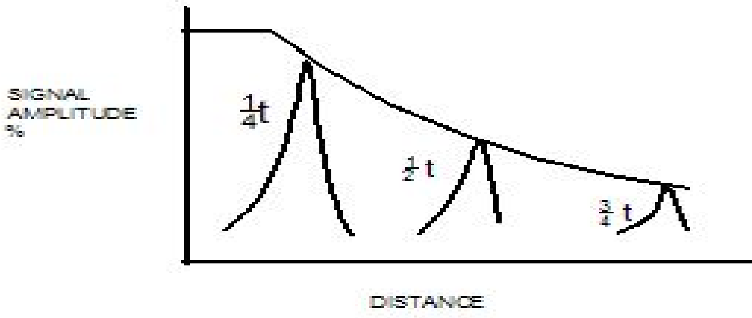
Scan Plan



Scanning Directions	Probes	
	Normal Beam 2/4 MHz	MWB45 2/4MHz
A,B	YES	NIL
C	NIL	YES

Reference Block and DAC Curve





NDE of welds in Pipes and Headers

Ultrasonic Testing (UT)

UT of End cover Plate weld –Scanning from Pipe Side

Case Studies on NDE OF P91 Materials

Case Study-I

Evaluation of Flat End Cover weld in Header

- Normal beam UT of weld from pipe side and end cover side was found to be OK.
- UT Angle beam examination revealed severe un acceptable signals from the root to a length of 400mm.
- It was suspected to be improper fusion at the root .
- Boroscopic examination from the ID of the pipe confirmed the presence of defects at the root suspected to be lack of fusion /crack.
- Decision was taken to repair the weld.
- Repair Done from outside by machining till the defect was visually seen.
- The defects found to be cracks to a length of 400 mm (approx) & 40mm respectively.

Case Study-I

Evaluation of Flat End Cover weld in Header

- Liquid Penetrant Inspection (LPI) clearly revealed these cracks
- Angle beam UT confirmed that a crack starting from root propagated to a depth of 15-17mm (cross sectional height)
- Further machining until the crack is completely removed and confirmed by LPI & UT
- RT of parent metal was also done to ensure that crack did not propagate to parent metal side

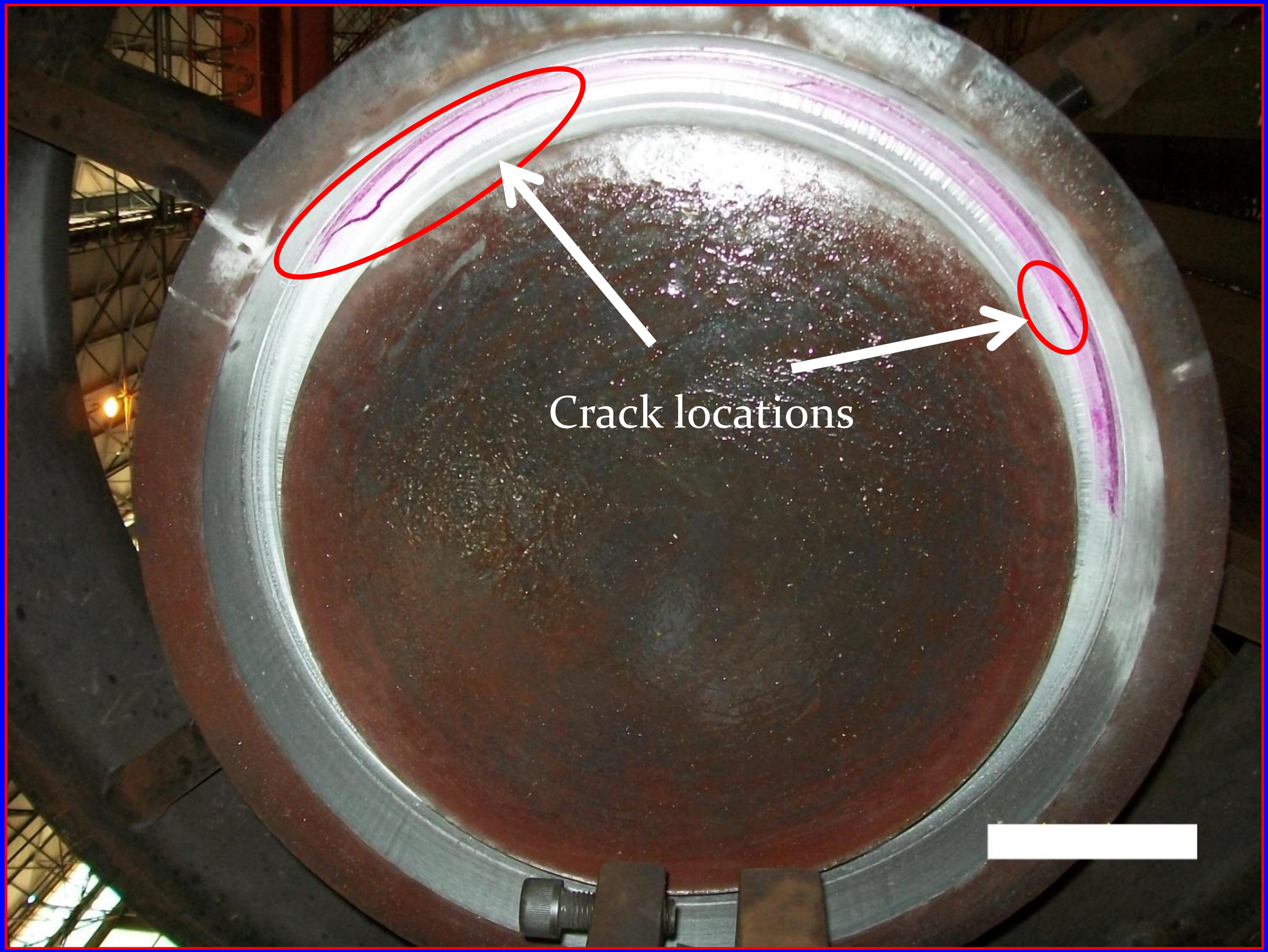
Case Study-I

Evaluation of Flat End Cover weld in Header

Root defects revealed by Video Boroscope

Case Study-I

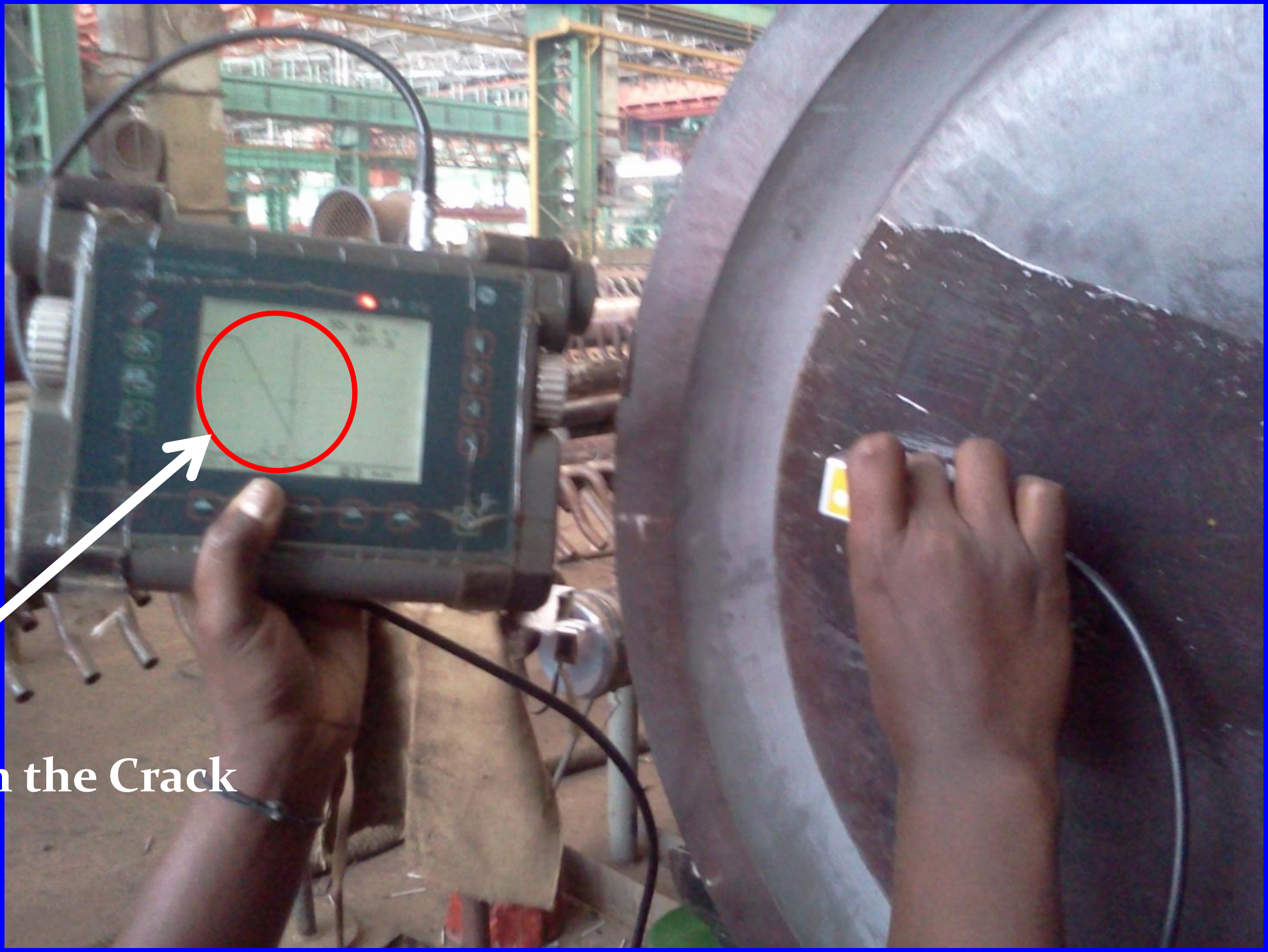
Evaluation of Flat End Cover weld in Header



Root Cracks revealed by LPI

Case Study-I

Evaluation of Flat End Cover weld in Header



Signal from the Crack

Sizing and characterization of root crack by Angle beam Scanning

Case Study-II

Detection of Cracks in Pipe Bends

- Pipe Bending operation carried out using Incremental Pipe Bending machine
- Transverse cracks occur in the tension region of the pipes due to deviation from the recommended process
- Crack detection by 100% inspection by Surface NDT methods like LPI/MPI and random UT
- LPI has limitations: Requirement of enormous cleaning to render the cracks open, long cycle time to pre-cleaning, dwell time etc.

Case Study-II
Detection of Cracks in Pipe Bends

- Alternative method: Dry continuous MPI with prods - the current has to be passed through the localized region to generate the circular magnetic flux in the job for detection of cracks .
- Test needs to be carried out in Two directions to take care of the orientation of the cracks and maximum 6 to 8 inch area can be covered in one shot.
- To cover the entire pipe surface of interest it takes about 3 to 3.5 hours and the method is quite cumbersome.
- For carrying out the test enormous grinding has to be done for surface preparation.
- Prods can create arc spots on the pipe surface, which will further damage the surface.

Case Study-II

Detection of Cracks in Pipe Bends

Innovative MPI Technique- Coil method

- Generation of longitudinal magnetization using the current carrying coils formed by the magnetizing cables, from a stationary magnetic particle system, with capacity 5000Amps HWDC /AC
- The coil is wrapped around the pipes and the powerful longitudinal field created by this coils can magnetize the entire circumference of the pipe to a distance of 18 inches on either sides of the coil
- Magnetic Field will be perpendicular to the direction of cracks; hence high reliability of detection
- The grinding for the pipe surface preparation can be completely eliminated by simple buffing, which results in cycle time reduction
- The entire inspection of the pipe can be carried out in 30-45 minutes
- To enhance the speed of inspection, two coils can be operated, with the help of two magnetic particle systems

Over all Benefits: Cycle time reduction of Pipe bending operation, Enhancement of quality of pipe bends and improved reliability of crack detection, Cost saving ,Customer satisfaction

Case Study-II

Detection of Cracks in Pipe Bends

Random UT

Case Study-II

Detection of Cracks in Pipe Bends

Incremental bending of pipes

MPI by Coil method

Case Study-III

Roof Seal Band weld of P91 Material

- Susceptible to cracking due to high restraint and dissimilar welds between Gr 22 roof seal band and T91 tube material
- LPI for detection of Surface crack

- SA213T91 Coil Roof Seal Band Weld
- (6 mm thick 2.25Cr-1 Mo Material)
- SMAW E9018 B3
- Cold crack along the weld, leaked in shop hydro test
- High restraint weld, crack along weld toe
- Noticed in December, rainy season
- Went back to basics

Case Study-IV

Welding and NDE of P91 pipe welds at Sites

BHEL Site Office, Simhadri 2 x 500 MW

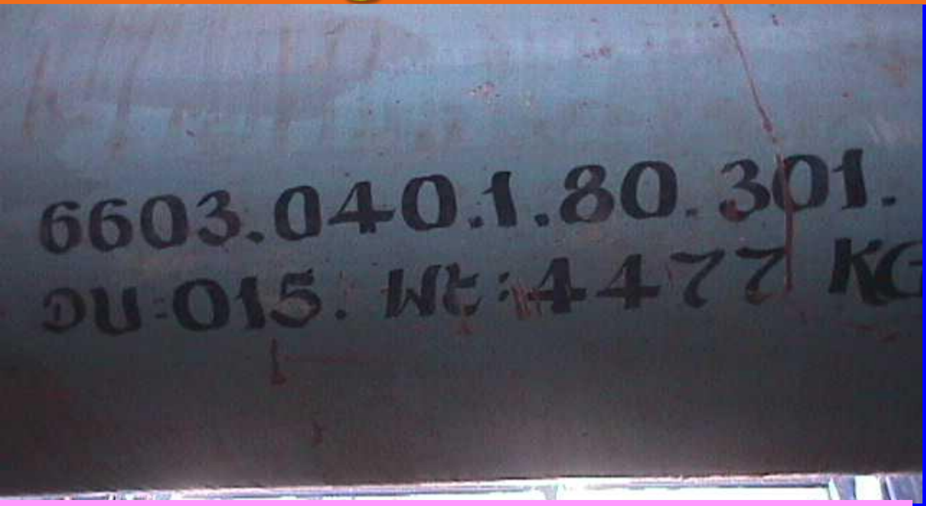
Case Study-IV
Welding and NDE of P91 pipe welds at Sites

PRECAUTIONS

- No temporary attachment should be welded with pipeline for erection or holding purpose.
- Arc strike on this material is to be totally avoided, well insulated welding holders and welding cables should be used.
- No bridges or rods should be welded to pipe for weld joint fit-up. Special clamps are to be made for the fit-up.
- Repair of edges by build-up is not permitted.
- Cutting and edge preparation to be done at site by mechanical means only. During grinding, avoid localized over heating of metal.
- Ensure baking & holding temperature of welding electrodes as recommended.
- Ensure DG supply before starting the preheating of weld joint or other alternate arrangements.

Case Study-IV

Welding and NDE of P91 pipe welds at Sites



IDENTIFICATION OF PGMA, DU, STUB ORIENTATION,PIPE LENGTH & END, ETC

CLEANING OF PIPE ENDS WITH BUFFING WHEEL

MEASUREMENT OF PIPE ID

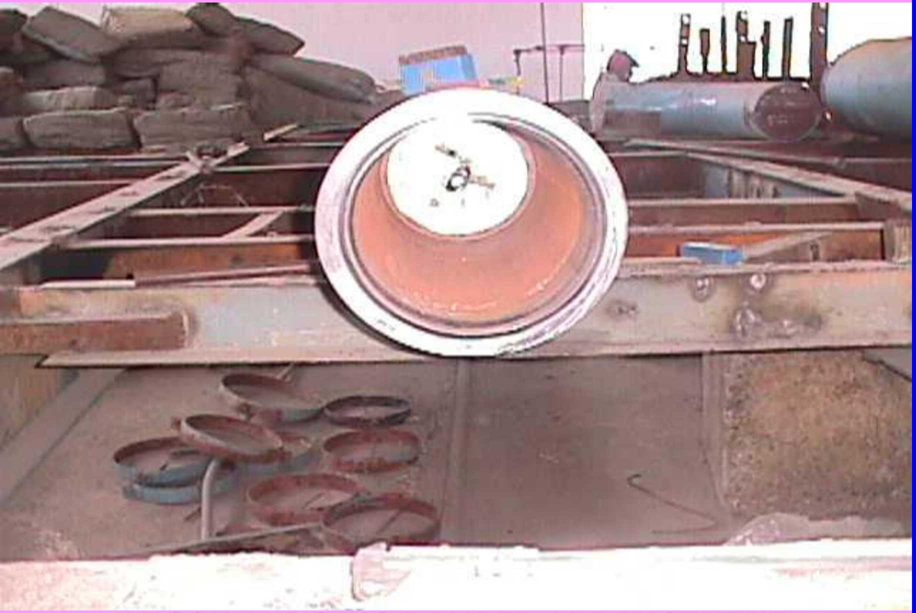
MEASUREMENT OF PIPE THICKNESS

Case Study-IV

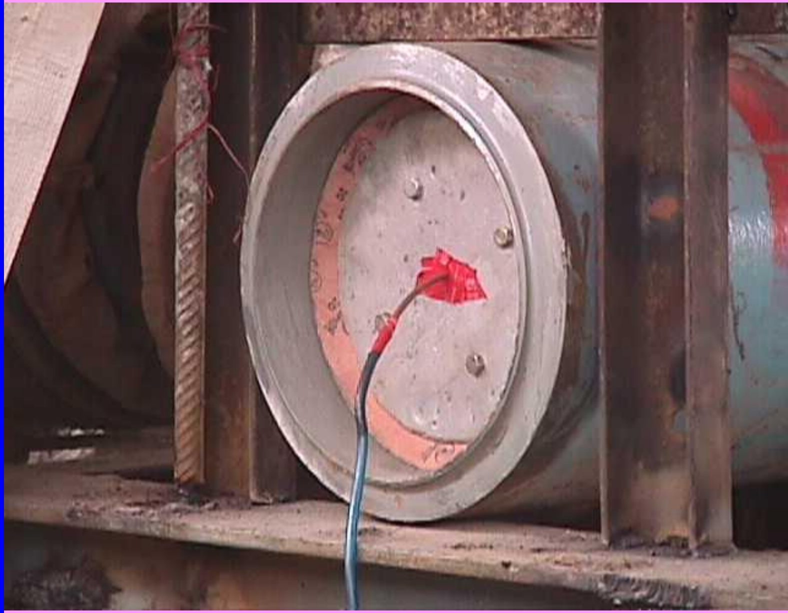
Welding and NDE of P91 pipe welds at Sites

GASKET WITH ALUMINIUM SHEET FOR ARGON PURGING DAMPER ARRANGEMENT

WIRE ROPE ARRANGEMENT FOR PULLING OUT DAMPERS AFTER COMPLETION OF TWO PASS SMAW



ARGON PURGING DAMPER ARRANGEMENT FIXED INSIDE THE PIPE



ARGON PURGING ARRANGEMENT

Case Study-IV

Welding and NDE of P91 pipe welds at Sites

MECHANICAL PIPE CLAMP BEING FIXED ON PIPE FOR JOINT FITUP

JOINT FITUP COMPLETED AND READY FOR INSPECTION

ID MISMATCH CHECKED USING HI-LOW GAUGE

JOINT ROOT GAP CHECKED USING TAPER GAUGE

Case Study-IV

Welding and NDE of P91 pipe welds at Sites

SURFACE PREPARED FOR THERMOCOUPLE WELDING ON PIPE BY FILING

THERMOCOUPLE WELDING ON PIPE

JOINT WRAPED WITH ANNEALING CABLE ON CERAMIC CLOTH COVERING WOOL INSULATION

JOINT ROOT GAP CHECKED USING TAPER GAUGE

Case Study-IV

Welding and NDE of P91 pipe welds at Sites

ARGON PURGING STARTED AT 25 lpm

GTAW IN PROGRESS

VISUALLY INSPECT ROOT WELDING THROUGH WINDOW OPENING PROVIDED AT BOTH SIDES OPPOSITELY.

After completion of GTAW, reduce Argon purging to 10 LPM and maintain purging till completion of Two passes of SMAW

Case Study-IV

Welding and NDE of P91 pipe welds at Sites

SMAW IN PROGRESS

INTER PASS CLEANING DURING SMAW

WELDING SEGMENT BALANCE TIME IN PROGRAMMER MADE TO ZERO AFTER COMPLETION OF WELDING

ARRANGEMENT OF ANNEALING CABLE FOR PWHT

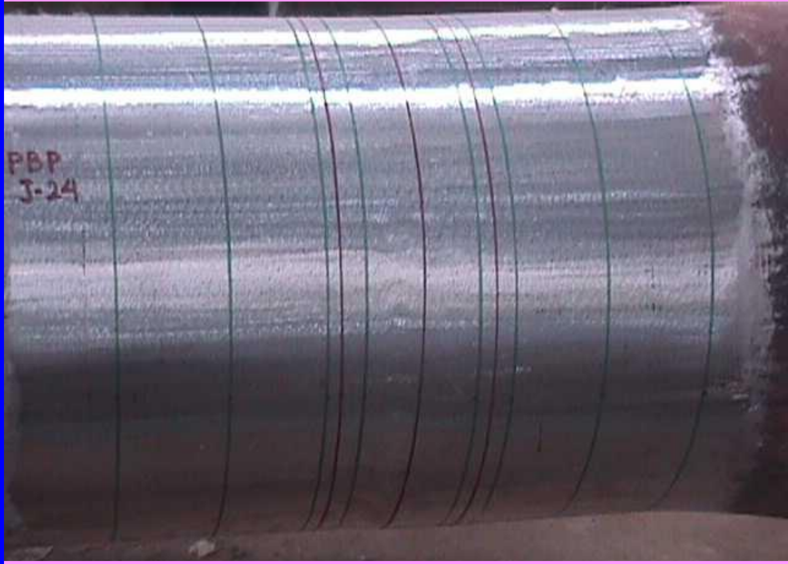
Case Study-IV

Welding and NDE of P91 pipe welds at Sites

WELD SURFACE FLUSH GROUND FOR NDE

METAL POLISHING AT 3, 6, 9 & 12 O' CLOCK POSITIONS

SURFACE READY FOR NDE



SURFACE MARKED WITH METAL MARKER FOR UT

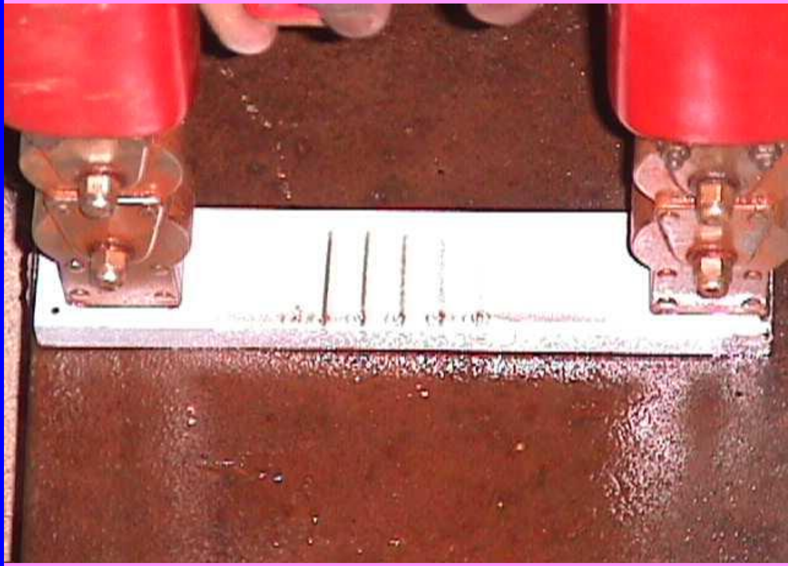
Case Study-IV

Welding and NDE of P91 pipe welds at Sites

UT IN PROGRESS

HARDNESS TESTER USED TO MEASURE CORRECTION FACTOR

HARDNESS TESTER USED TO MEASURE HARDNESS VALUE ON THE PIPE



SENSITIVITY OF MPI MACHINE CHECKED

Case Study-IV

Welding and NDE of P91 pipe welds at Sites

WET VISIBLE MPI WITH YOKE

CONCLUSION

- NDE Plays a vital role towards ensuring the quality of power plant equipments fabricated using P91 material
- Proper selection of NDE technique and its deployment at the right stage during manufacturing cycle helps in process control
- Since P91 is susceptible for cracking, NDE Techniques like Ultrasonic testing and Fluorescent MPI ensure the reliable detection of cracks
- Inter stage NDE (RT/ hot MPI) helps in early detection of defects at the root of thick wall components
- Visual inspection with video boroscope will help in detection of ID defects
- Feedback from NDT results shall be used towards improved process control; rather than as a postmortem of weld

BACK

Evaluation of Reheater outlet header with P91 and T91 material after 15 years of service

A CASE STUDY

CASE HISTORY

- This unit was designed for 100% coal, oil & gas firing.
- Reheat steam flow is 1490 TPH at Pressure of 41.72 kg/cm2 and temperature 568 Deg C.
- Reheater composed of a radiant wall reheater (front and both sides), front pendant Platen, inter pendant spaced and rear final spaced.
- RH outlet right side showed signs of overheating after certain period of operation.

CASE HISTORY

- Initially P22 material was provided for Reheater O/L header.
- After 5 years of operation the end portions of Reheater outlet header was replaced with P91 along with T91 material for the stubs for the replaced P91 portion.
- After modification, unit is in continuous operation satisfactorily for the past 15 years and recently RLA study was conducted by BHEL in Jan' 2011 for assessing the condition of the header.

REHEATER BEFORE MODIFICATION:

Header:

Ø 558.8 x 55mm

SA213 P22

Stub:

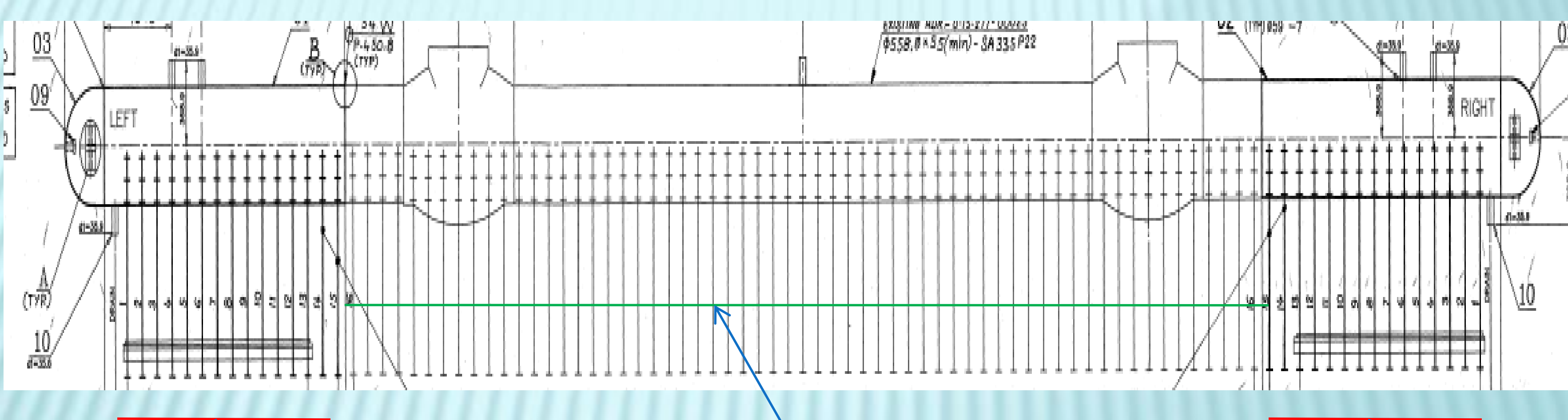
Ø 76.1 x 8mm

SA213 T22

RH outlet header after modification:

Component Name	Material specification	Dimensions
RH outlet header	P22 and P91	D 558.8x55
Middle portion	SA 213 P22	D 558.8x55
Left End portion	SA 213 P91	D 558.8x55
Right End portion	SA 213 P91	D 558.8x55

Reheater Outlet Header



P22 Portion

P91 Portion

P91 Portion

RLA study of Reheater Outlet header:

Tests conducted:

1) Visual inspection
2) Dimensional measurement
3) Non Destructive Testing
4) Videoscopic inspection
5) In-situ oxide scale measurement
6) Replication

Visual inspection :

Inspection is carried out in RH outlet header and in coils .

No signs of overheating is observed in the header and coil portions and condition of the header is found to be good.

Dimensional measurement:

Dimensional measurement was carried out and found that the values are within the specified limits.

NDT

NDT was carried out in the header butt weld joints and stub weld joints and no significant defects were observed.

Videoscopic inspection :

S. No	COMPONENT	VIEWED THROUGH	OBSERVATION	REMARKS
01	Re-Heater Outlet Header	Stub holes of 20^{th} ,40^{th} & 72 at front side of the header	No Ligament crack found No Debris found Thin Scale found Small Pitting found No foreign material found **Header inside black color found**	**Satisfactory**

Insitu oxide scale measurement:

In-situ oxide scale measurement was carried out at all header stubs and the values were found to be not so significant showing the availability of further remaining life to the tune of 100,000 hours.

Component OD X thick Material IOT Location	**Coils nos.**	**Oxide scale thick in mm**	**Remaining useful life in hours**
Re Heater outlet header stub	1-91	<0.23	>100,000 hrs

Replication :

Replication :
In-situ metallographic replication carried out in 9 spots covering P91 portion of the header in both ends and P22 portion of the header in the middle including the weld joints in both ends at the interface.

Two more replica were taken in the header stubs of T91 portion due to non availability of tube sample for replacement.

Replication at Reheater Outlet header

Microstructure laboratory report

Replica No.	*Details*	*Location*	*Mag (X)*	*Microstructure*	*Photo No.*	*Spheroidis-ation Level*	*Creep Rating*
RH OUTLET HEADER							
R1	DE Weld Joint - LHS	PM	200	Tempered martensite	1	I	1
		Weld	-	Tempered Martensite	-	-	-
		HAZ	-	Coarse Tempered Martensite	-	-	-
		HAZ*	-	Fine Tempered Martensite	-	-	-
R2	DE- Parent Metal - LHS	PM	200	Tempered martensite	2	I	1
R3	Header PM Near Stub 6 - LHS	PM	200	Tempered martensite	3	I	1
R4	Header P91+P22 - LHS Joint covering P91 HAZ	PM	200	Tempered martensite	4	I	1
		Weld	200	Tempered Martensite	5	-	-
		P91HAZ	200	Tempered Martensite	6	-	-
		P91HAZ*	-	Fine Tempered Martensite	-	-	-
R5	T joint - LHS P22+P22	PM	200	Tempered Bainite	7	I	1
		Weld	200	Tempered Bainite	8	-	-
		P22HAZ	200	Tempered Bainite	9	-	-
R6	Header P91+P22 - RHS Joint covering P22 HAZ	PM	200	PGF + ISB	10	II	1
		Weld	200	Tempered Bainite	11	-	-
		P22HAZ	200	Tempered Bainite	12	-	-
R7	Header PM Between Stub 84 & 85 - RHS	PM	200	Tempered martensite	13	I	1

Replica No.	*Details*	*Location*	*Mag (X)*	*Microstructure*	*Photo No.*	*Spheroidis-ation Level*	*Creep Rating*
R8	DE Weld Joint - RHS	PM	200	Tempered martensite	14	I	1
		Weld	200	Tempered Martensite	15	-	-
		P91HAZ	200	Tempered Martensite	16	-	-
		P91HAZ*	-	Fine Tempered Martensite	-	-	-
R9	DE- Parent Metal - RHS	PM	200	Tempered martensite	17	I	1
R10	Vertical Coil No. 9	PM	200	Tempered martensite	18	I	1
R11	Vertical Coil No. 82	PM	200	Tempered martensite	19	I	1

PHOTOMICROGRAPHS:

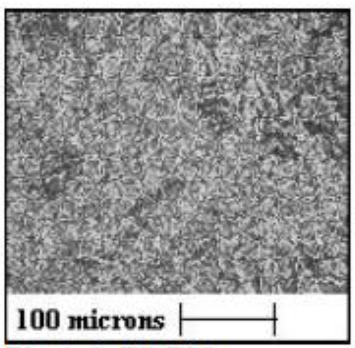


Photo 1: R1-PM

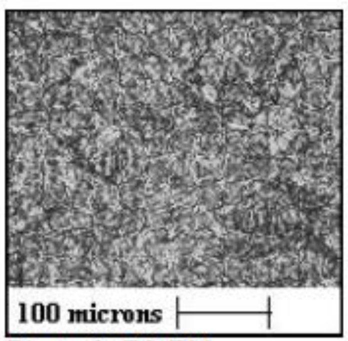


Photo 2: R2-PM

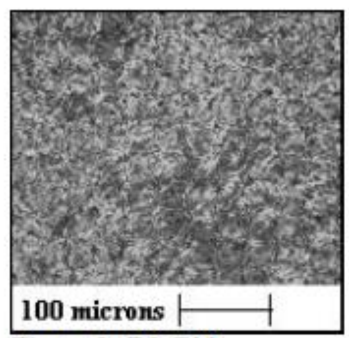


Photo 3: R3-PM

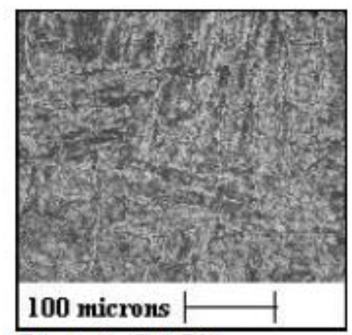


Photo 4: R4-PM

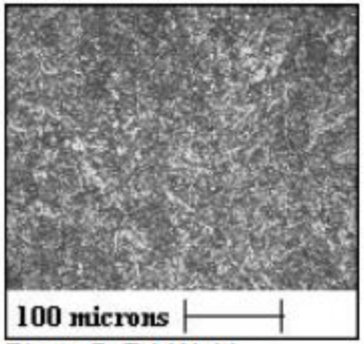


Photo 5: R4-Weld

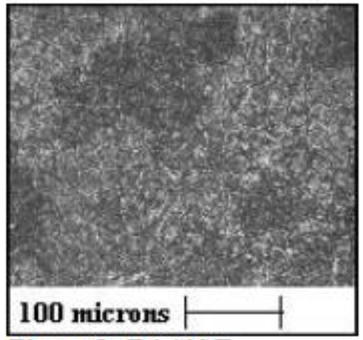


Photo 6: R4-HAZ

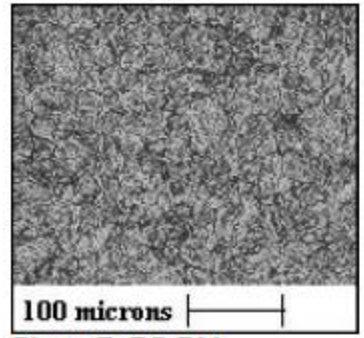


Photo 7: R5-PM

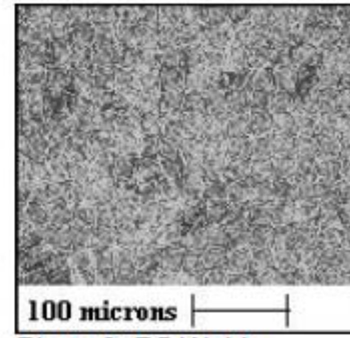


Photo 8: R5-Weld

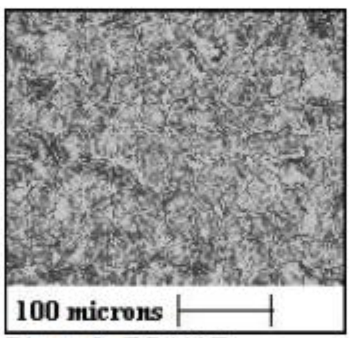


Photo 9: R5-HAZ

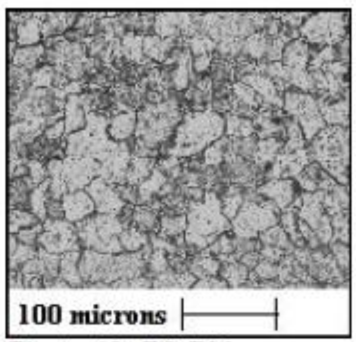


Photo 10: R6-PM

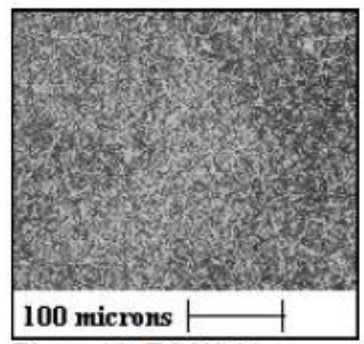


Photo 11: R6-Weld

Microstructure Analysis :

Findings:

RH Outlet Header:

1. P91 portions of the header show satisfactory microstructures in the base metal. HAZ and Weld metal. Hardness values are also seems to be satisfactory. However the hardness values in the fine HAZ regions of the P91 weld joints show slightly lower hardness values when compared to that of coarse HAZ region.

2. P22 header material shows mild degradation in the microstructure. Hardness values are seems to be satisfactory.

Conclusion:

The header is found to be in good condition and no significant degradation is observed through the tests carried out in RLA for the P91/T91 material which is under service for the past 15 years.

BACK

Development of castings in supercritical steels – CFFP perspective

Introduction

Central Foundry Forge Plant, a foundry-forge unit of BHEL is catering to requirements of steel castings and forgings for power plant equipments of various ratings. A major portion of the production of steel castings is for steam turbines of 210, 250 and 500 MW in Cr-Mo-V grade such as inner and outer casings, valve casings, valve covers, inserts, etc. In the development of higher efficiencies of power plants, requirement of castings in advanced material which can withstand higher temperature and pressure (supercritical parameters) is growing.

CFFP has already manufactured castings in G-X12CrMoWVNbN 10 1 1 and ASTM A217M-C12A grades. The paper deals with principles involved in development of castings in supercritical grade of steel at CFFP. Three principle areas are covered – casting technology, steel melting and welding technology.

Castings for power plant equipment with supercritical parameters: Material and properties

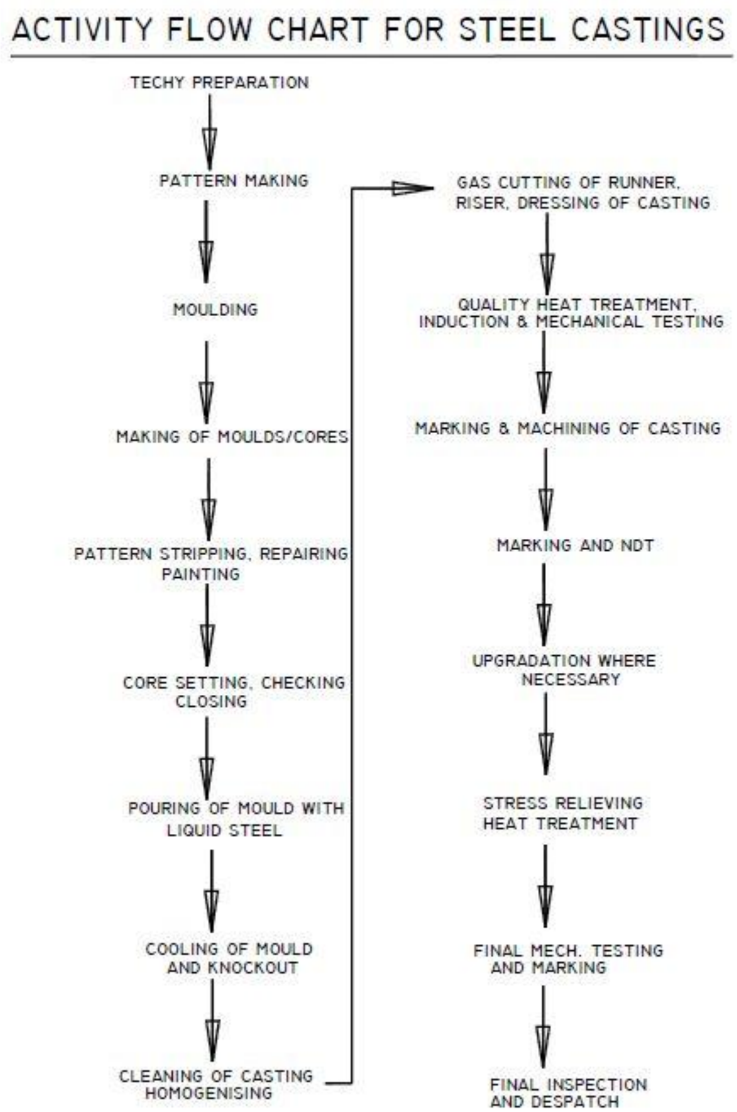
CFFP is in process of developing castings in three varieties of supercritical steel. The chemical composition and mechanical properties of the three types of steel are as given in table 1 and 2 respectively. The table also shows the composition and properties of convention Cr-Mo-V steel which is prevalent in sub-critical parameter power plant components.

ELEMENTS	G17CrMoV5-10	ASTM A217M-C12A	G-X12CrMoWVNbN 10 1 1	G-X12CrMoVNbN 9-1
C	0.15-0.20	0.08-0.12	0.11-0.14	0.11-0.14
Si	0.60 MAX	0.20-0.50	0.20-0.40	0.20-0.50
P	0.020 MAX	0.030 MAX	0.020 MAX	0.02 MAX
S	0.015 MAX	0.010 MAX	0.010 MAX	0.010 MAX
Mn	0.50-0.90	0.30-0.60	0.80-1.20	0.40 – 0.80
Cr	1.20-1.50	8.00-9.50	9.20-10.2	8.0 – 9.5
Mo	0.90-1.10	0.85-1.06	0.90-1.05	0.9 – 1.05
V	0.20-0.30	0.18-0.25	0.18-0.25	0.18 – 0.25
Ni	0.70 MAX	0.40 max	0.60-0.80	0.40 MAX
Al(T)	0.025 MAX	0.040 MAX	0.020 MAX	0.020 MAX
Nb	-	0.06-0.10	0.04-0.08	0.05 – 0.08
N	-	0.03-0.07	0.04-0.06	0.04 – 0.06
W	-	-	0.95-1.05	-
Ti		0.01 max		
Zr		0.01 max		

	G17CrMoV5-10	ASTM A217M-C12A	G-X12CrMoWVNbN 10 1 1	G-X12CrMoVNbN 9-1
0.2% YS (N/mm^2)	440 (min.)	415 (min.)	520 (min.)	500 (min)
UTS (N/mm^2)	590-780	585-760	680-850	630-750
%El	15 (min.)	18 (min.)	15 (min.)	16 (min)
%RA	40 (min.)	45 (min.)	40 (min.)	40 (min)
IMPACT (Charpy V notch) - J	27 (min.)	35 (min.)	35 (min.)	35 (min)

Casting Technology

A typical steel casting is manufactured as per the sequence shown in Table 3.



The development of technology/methoding for castings in supercritical steel is more difficult as compared to conventional Cr-Mo-V grade castings. Following considerations are a must while working out the technology for the castings.

- The high alloyed supercritical steel have a different solidification morphology than Cr-Mo-V steels and hence the feeding characteristics of this steel is more difficult, increasing with the variation in wall thickness and size of the casting.
- The conventional Cr-Mo-V grade has a bainitic structure, whereas the supercritical steels have martensitic structure, which makes the castings prone to cracking and rejection during various stages of production in the foundry.
- The cracking tendencies in 9-10% Cr steel castings are roughly double to that of G-17CrMoV5-10 grade castings. Higher pouring temperatures of the supercritical steel make it more vulnerable to surface defects and hot-tears.
- Slow cooling in the mould may lead to delta ferrite precipitation which is a brittle structure whereas faster cooling may lead to heavy cracks.
- Due to the fact that severe differences in wall thickness are typical for turbine casings, the temperature distributions in different sections are highly critical in the temperature range of martensitic transformation.
- Logistics of handling the casting during various stages of production has to be planned dependent on the microstructural condition of different sections. In consequence, the castings need to be handled with due care in view of highly stressed and brittle nature of martensite which is further accentuated by the precipitation of carbides on grain boundaries.
- Multiple tempering and long holding times for heavy castings due to more cycles of repair and construction welds cause a reduction in yield strength.
- Due to high residual stresses of 9% Cr steels resulting from martensitic microstructure, major process and construction welds are to be performed in partial stages with intermediate stress relieving.
- Strict technological discipline – at each stage of production, i.e., moulding, pouring, knock-out, cleaning/BMG, heat treatment and fettling operations.
- Clean liquid metal and controlled pouring will play a major role in determining the quality of the casting.

The cost increase in manufacturing of these casting is 30-50% compared to the conventional Cr-Mo-V grade of steel. The cost increase is mainly on account of:

- Higher incidence of rejection/scrap
- Higher material costs
- Likely lesser % of yield
- Increase in processing time at all the stages
- Higher fuel consumption due to longer cycles.
- More defect levels
- Difficult handling for shake-out, cleaning, riser cutting, longer heat treatment cycles, intermediate reheating and SR cycles.

Steel Melting

Steel melting and refining of the liquid metal plays a major role in development in castings in supercritical grade. CFFP had to face a few challenges while development of tungsten bearing grade of this steel. Some of these are listed below

- Tungsten has a tendency to stick to furnace bottom refractories or be partially absorbed by them due to its high density. Its density is 19.25 gm/Cm^3 and liquid density is 17.6 gm/cm^3.
- Partial oxidation of tungsten under steel making condition makes the molten pool depleted in tungsten.
- Sluggish solution rate due to high melting point.
- Difficulty in controlling the nitrogen content due to degassing effect at VAD.

A number of innovative steps were evolved during development of liquid steel in supercritical grades. The ferrotungsten addition was done in the ladle at VAD station instead of adding it to the furnace. Due to stirring action by argon gas inside VAD, there was no sticking of the ferrotungsten to the bottom of the ladle. Further partial oxidation of ferrotungsten was avoided due to presence of Al and Si in the melt at VAD. The size of the ferrotungsten was limited to less than 50 mm. Calculated amount of NItrided ferrochrome was added after deep degassing operation at VAD. This enabled control of nitrogen in the metal.

Present Method:

The following sequence of operation describes the steel melting practice being followed for manufacturing supercritical grade castings

- Melting of selected scrap in EAF.
- Dephosphorisation in EAF.
- Slag free tapping in the ladle.
- Heating and alloy adjustment at VAD.
- If carbon content is within range then do the deep degassing.
- Decarburization at VOD if the carbon content is high.
- Addition of nitrogen. (In form of nitrided Ferro chromium)
- Homogenize the bath with respect to temperature and chemistry.
- Pouring in the moulds.

Welding Technology

Welding in steel castings is mainly on account of defect welding and dimensional build-up of casting, if required. This is apart from any fabrication welding which may be called for by design.

Welding consumables

- Supercritical steels are welded with matching consumables in order to have homogenous weld with about equal mechanical properties. Matching compositions also have the same coefficient of thermal expansion which prevents the risk of thermal fatigue. SMAW process is being used for welding. The hardness of weld zone and HAZ should not exceed 300 BHN.

- Consumables with low residual Phosphorus and Sulphur (<0.010%), Sn, As, Sb are being used to prevent cracking.
- XX15 types of electrodes are being used, as XX18 types of electrodes have extra Fe powder in the coating which is a source of contamination.
- A minimum carbon content of 0.08%, Nb 0.03% and Nitrogen 0.03% is being ensured to achieve adequate creep resistance.
- Consumables are being procured from M/s Bohler, M/s Thyssen and M/s Oerlikon.
- Non-synthetic electrodes are being used.

Welding Parameters

- Preheat and post heat temperatures – 200-300 °C
- Cool upto at least 80 °C after complete welding to ensure complete martensitic transformation.
- Use of wide flat bead with slight weaving. Bead thickness is maximum 1/8”.
- PWHT at 730 °C for 2 hours/inch of weld deposit.

<u>Authors:</u>

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DEVELOPMENT OF CASTINGS IN SUPERCRITICAL STEEL AT CFFP

25 - 26th February, 2011

CASTINGS

BACKGROUND - CASTINGS

- At present most of the castings for steam turbines made in creep resistant grades (G17CrMoV5-10) are applicable for service temperatures upto 540 °C.

- Construction of advanced, higher efficiency power stations requires supercritical steels for high and intermediate pressure components to work in service temperatures of 600-620 °C and supercritical steam pressure of >300 bar.

- CFFP is in process of developing castings in three grades of supercritical steels currently

  G-X12CrMoWVNbN 10 1 1

  G-X12CrMoVNbN 9 1

  ASTM A217 C12A

  The composition and mechanical properties are as given ahead

TECHNICAL PARAMETERS - CASTINGS

- **COMPOSITION**

ELEMENTS	G17CrMoV 5-10	ASTM A217M-C12A	G-X12CrMoWVNbN 10 1 1	G-X12CrMoVNbN 9-1
C	0.15-0.20	0.08-0.12	0.11-0.14	0.11-0.14
Si	0.60 MAX	0.20-0.50	0.20-0.40	0.20-0.50
P	0.020 MAX	0.030 MAX	0.020 MAX	0.02 MAX
S	0.015 MAX	0.010 MAX	0.010 MAX	0.010 MAX
Mn	0.50-0.90	0.30-0.60	0.80-1.20	0.40 – 0.80
Cr	1.20-1.50	8.00-9.50	9.20-10.2	8.0 – 9.5
Mo	0.90-1.10	0.85-1.06	0.90-1.05	0.9 – 1.05
V	0.20-0.30	0.18-0.25	0.18-0.25	0.18 – 0.25
Ni	0.70 MAX	0.40 max	0.60-0.80	0.40 MAX
Al(T)	0.025 MAX	0.040 MAX	0.020 MAX	0.020 MAX
Nb	-	0.06-0.10	0.04-0.08	0.05 – 0.08
N	-	0.03-0.07	0.04-0.06	0.04 – 0.06
W	-	-	0.95-1.05	-
Ti		0.01 max		
Zr		0.01 max		

TECHNICAL PARAMETERS - CASTINGS

- **MECHANICAL PROPERTIES**

	G17CrMoV 5-10	ASTM A217M-C12A	G-X12CrMoWVNbN 10 1 1	G-X12CrMoV NbN 9-1
0.2% YS (N/mm²)	440 (min.)	415 (min.)	520 (min.)	500 (min)
UTS (N/mm²)	590-780	585-760	680-850	630-750
%El	15 (min.)	18 (min.)	15 (min.)	16 (min)
%RA	40 (min.)	45 (min.)	40 (min.)	40 (min)
IMPACT (Charpy V notch) - J	27 (min.)	35 (min.)	35 (min.)	35 (min)

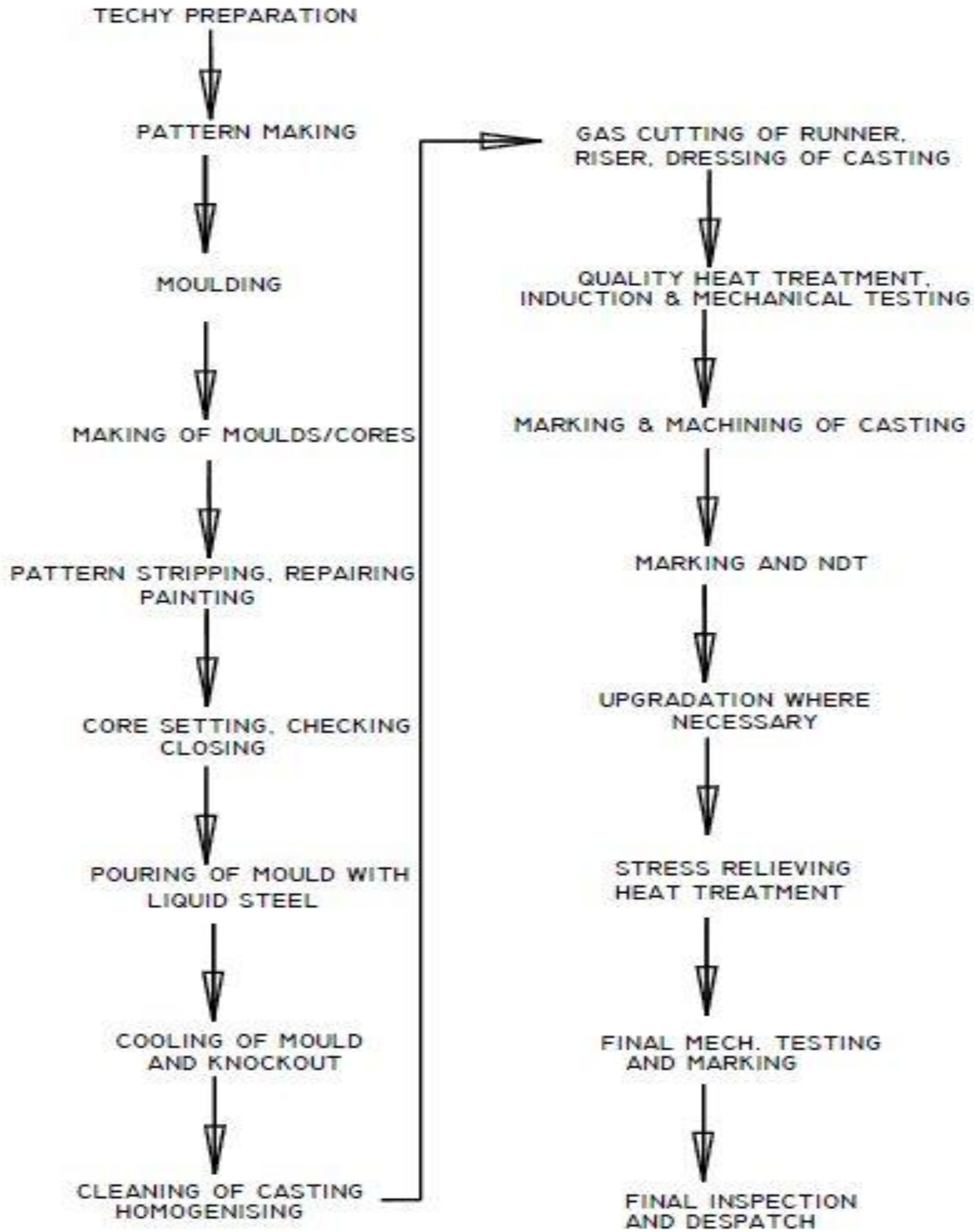
TECHNICAL PARAMETERS - CASTINGS

- **HEAT TREATMENT**

	G17CrMoV 5-10	G-X12CrMoWVNbN 10 1 & ASTM A217M-C12A	G-X12CrMoVNbN 9-1
HARDENING	AT 920-960 °C	AT 1080 – 1100 °C	AT 1040 – 1070 °C
QUENCHING	AIR/LIQUID	AIR QUENCH UPTO LESS THAN 90 °C	AIR QUENCH UPTO LESS THAN 90 °C
TEMPERING	AT 680-740 °C	AT 730-740 °C	AT 730 – 750 °C

FOUNDRY TECHNOLOGY

ACTIVITY FLOW CHART FOR STEEL CASTINGS



PRESENT STATUS - CASTINGS

- CFFP has successfully developed technology for making supercritical steel in two out of three grades, i.e., GX12CrMoWVNb10-1-1 and ASTM A217M-C12A.
- Orders for castings in Supercritical grade GX12CrMoVNbN9-1 for 660 MW Prayagraj project has been placed on CFFP. This grade of steel is also feasible to manufacture. The pattern making is already in progress for the ordered items.
- 3 castings in supercritical grade of steel (GX12CrMoWVNb10-1-1) – 1 set of HP Inner Casing and 1 ESV&CV Casing has already been dispatched successfully.
- 2 castings of HRH Housing (ASTM A217M-C12A) and 6 castings (IP Inner Casing and Valve Covers) in GX12CrMoWVNb10-1-1 grade have been poured and currently under process.

ISSUES TO BE ADDRESSED - CASTINGS

- The high alloyed supercritical steel have a different solidification morphology than the present creep resistant grade G17CrMoV5-10.

- Feeding characteristics of supercritical steels are more difficult increasing with the variation in wall thickness and size of the casting.

- Present grade G17CrMoV5-10 has bainitic microstructure whereas the supercritical steels has martensitic microstructure which makes the castings prone to cracking and rejection.

- Due to high residual stresses of 9% Cr steels resulting from martensitic microstructure, major process and construction welds are to be performed in partial stages with intermediate stress relieving.

ISSUES TO BE ADDRESSED - CASTINGS

- The cracking tendencies in 9-10% Cr steel castings is roughly double to that of G-17CrMoV5-10 grade castings. Higher pouring temperatures of the supercritical steel makes it more vulnerable to surface defects and hot-tears.

- Slow cooling in the mould may lead to delta ferrite precipitation which is a brittle structure whereas faster cooling may lead to heavy cracks.

- Due to the fact that severe differences in wall thickness are typical for turbine casings, the temperature distributions in different sections is highly critical in the temperature range of martensite transformation.

ISSUES TO BE ADDRESSED - CASTINGS

- The cost increase is 30-50% as compared to the present grades of steel depending on size and complexity of the castings – which is due to –
  - Higher incidence of rejection/scrap
  - Higher material costs
  - Likely lesser % of yield
  - Increase in processing time at all the stages
  - Higher fuel consumption due to longer cycles.
  - More defect levels
  - Difficult handling for shake-out, cleaning, riser cutting, longer heat treatment cycles, intermediate reheating and SR cycles.

ISSUES TO BE ADDRESSED - CASTINGS

- Logistics of handling the casting during various stages of production has to be planned dependent on the microstructural condition of different sections. In consequence, the castings need to be handled with due care in view of highly stressed and brittle nature of martensite which is further accentuated by the precipitation of carbides on grain boundaries.

- Multiple tempering and long holding times for heavy castings due to more cycles of repair and construction welds cause a reduction in yield strength.

- Strict technological discipline at every stage of production viz., moulding, pouring, knock-out, gas cutting, heat treatment, welding, stress relieving is required.

STEEL MAKING

Steelmaking of Supercritical Steel - Problems faced

- Tungsten has a tendency to stick to furnace bottom refractories or be partially absorbed by them due to its high density. Its density is 19.25 gm/Cu cm and liquid density is 17.6 gm/Cu cm.

- Partial oxidation of tungsten under steel making condition.

- Sluggish solution rate due to high melting point.

- Difficulty in controlling the nitrogen content due to degassing effect at VAD.

Steelmaking of supercritical steels - Method applied

- Started the addition of ferrotungsten in the ladle at the VAD instead of adding it to furnace. Due to stirring action by argon gas there was no sticking to the bottom of ladle.

- Due to presence of Al & Si in the melt at VAD there was no partial oxidation of ferrotungsten.

- Restricted the size of ferrotungsten < 50 mm.

- Addition of calculated amount of nitrided ferro chromium **after** the deep degassing operation at VAD.

Process Route for Steel making of supercritical (Tungsten) steel

- Melting of selected scrap in EAF.
- Dephosphorisation in EAF.
- Slag free tapping in the ladle.
- Heating and alloy adjustment at VAD.
- If carbon content is within range then do the deep degassing.
- Decarburization at VOD if the carbon content is high.
- Addition of nitrogen. (In form of nitrided Ferro chromium)
- Homogenize the bath with respect to temperature and chemistry.
- Shift the metal for pouring.

WELDING TECHNOLOGY

Welding in Supercritical grade castings

- SMAW process is being used for welding . Hardness of weld zone and HAZ not to exceed 300 BHN.
- Use of matching consumables in order to have homogenous weld and matching mechanical properties including coefficient of thermal expansion.
- Consumables with low residual P and S (<0.010%), Sn, As, Sb are being used to prevent cracking.
- XX15 types of electrodes are being used, as XX18 types of electrodes have extra Fe powder in the coating which is a source of contamination.

Welding parameters

WELDING ELECTRODES

- *G-X12CrMoWVNbN 10 1 1 :*
  - MTS 911 (THYSSEN)
  - FOXC9MVW (BOHLER)
  - CHROMOCORD 10 M (OERLIKON)
- *ASTM A217 GR C12A & G-X12CrMoVNbN 9 1:*
  - CROMO 9V (THYSSEN)
  - FOX C 9MV (BOHLER)
  - CROMOCORD 9M (OERLIKON)

Welding parameters

- Preheat and Post heat temperatures – 200 – 300 °C.
- Cool upto at lest 80 °C after complete welding to ensure complete martensitic transformation.
- Use of wide flat bead with slight weaving. Bead thickness is maximum 1/8”.
- PWHT at 730 °C for 2 hours/inch of weld deposit.

BACK

FLASH FORGE

SOURCE.DESIGN.PROCESS

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Flash Forge Pvt. Ltd.

P 91 Fabrication & Welding

Authors

Haresh Shah COO HE & Fab. Div.

Mr. S.N. Bagchi, General Manager, QA

Introduction

Flash Forge Pvt. Ltd. is engaged in development and fabrication of tubular components for defense, power sector, and other applications.

At FFPL, our welding procedures are made to specification, ASME SEC IX. We assess weld process integrity, incorporate our experience, and merge it with global experience, with emphasis on metallurgy.

We have forged and fabricated P 91 steel components for creep strength enhanced ferritic steels (CSEFS) for main-steam piping and super heaters by induction heating as well as by resistance heating.

Quality management, metallurgical controls, welding consumables, welding, heat treatment, mechanical properties, microstructure and weld precautions are discussed in this write-up.

This paper reviews our various controls necessary for fabrication shop management to ensure compliance with ASME code and customers' specifications.

We have been fabricating P 91 steel components since 2008 and our WPS, PQR, our microstructures, controls, failure reports, photos and reports are exhibited in this report.

Facilities for P 91

- Experience Welding Engineer.
- 6 Qualified Welder.
- Preheating & PWHT by Resistance & Induction System.
- Welding rectifiers.
- Generator Sets for Power Back Up.
- Selection of weld consumables.
- CNC & Boring Machine for Edge Preparation.
- Testing & Inspection.

Control parameters in welding

a. Control temperature:

The weldments are to be heated to 200^{0}C, the heating rate at this stage is not critical. Temperature is <300^{0}C during welding.

b. Control temperature rise:

The weldments are heated at a controlled rate of heating from 315^{0}C, heating rate <300^{0}C per hour. Thicker sections → slower heating rates.

c. Soaking temperature and soaking time:

For heavy wall weldments, recommended temperature is 745^{0}C $\pm$15^{0}C, in Other cases, it may be >595^{0}C & < 760^{0}C, depending on the composition. Soaking time is about 1 hr. / inch, minimum 2hrs for20 mm thickness.

d. Post soak controlled cooling:

Controlled cooling rate to lower thermal stresses, which can lead to cracking. Cooling rate from 750^{0}C to 300^{0}C is $\leq$ 100^{0}C per hour, & air cooling.

Report on P 91 welding by Induction heating

- **Observations**:

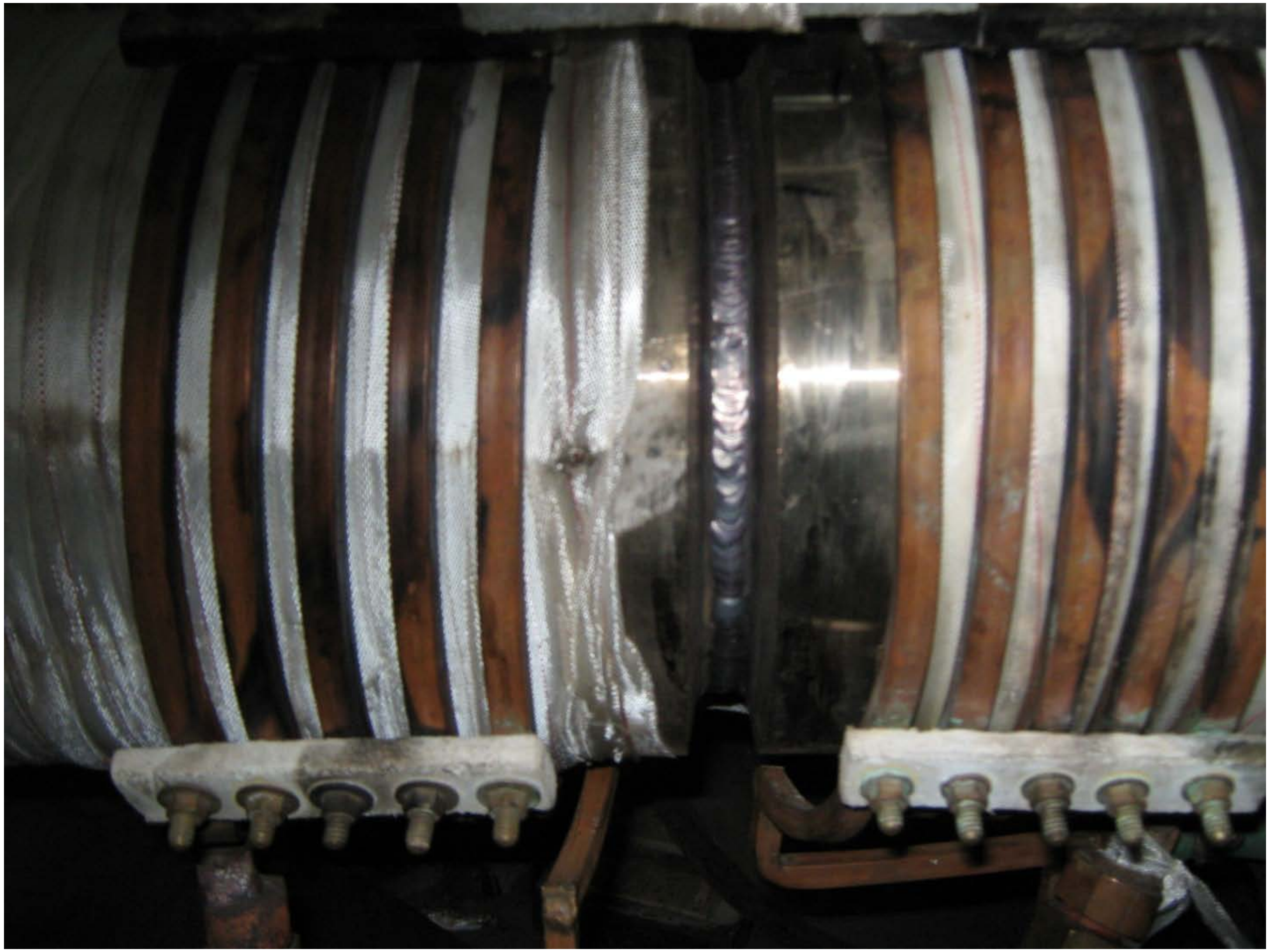
- We welded 800 mm diameter P 91 pipes by induction heating at VEL, Mumbai. Both pre-heating and PWHT were done by a medium frequency induction heater of 50 KW capacity, made available to us by M/S VEL.
- We used TIG welding with 4mm size electrodes. The root run (in 2 layers) was by 2.4 mm wires, filler wires were ER 90S – B9, GTAW, DCEN (DC Electrode --ve) The arc current was between 105 to 134 amperes, voltage was between 11.5 to 14.5 volts, Welding speed range between 21 to 25mm /minute..
- The 2^{nd} and 3^{rd} layers were by 3.2 mm electrodes ER 9016 B9, SMAW, DCEP. DCEP (DC Electrode +ve) The arc current was between 90 to 118 amperes, voltage was between 28 to 32 volts, Welding speed range between 65 to 108 mm /minute..
- The 4^{th} and 5^{th} layers were by 4.0 mm electrodes ER 9016 B9, SMAW, DCEP. The arc current was between 136 to 141 amperes, voltage was between 34 to 35 volts, Welding speed range between 50 to 89 mm /minute..
- The 6^{th} and 7^{th} layers were by 3.2 mm electrodes ER 9016 B9, SMAW, DCEP. The arc current was between 105 to 115 amperes, arc voltage was between 32 to 34 volts, Welding speed range between 65 to 92 mm /minute.

Report and remarks:

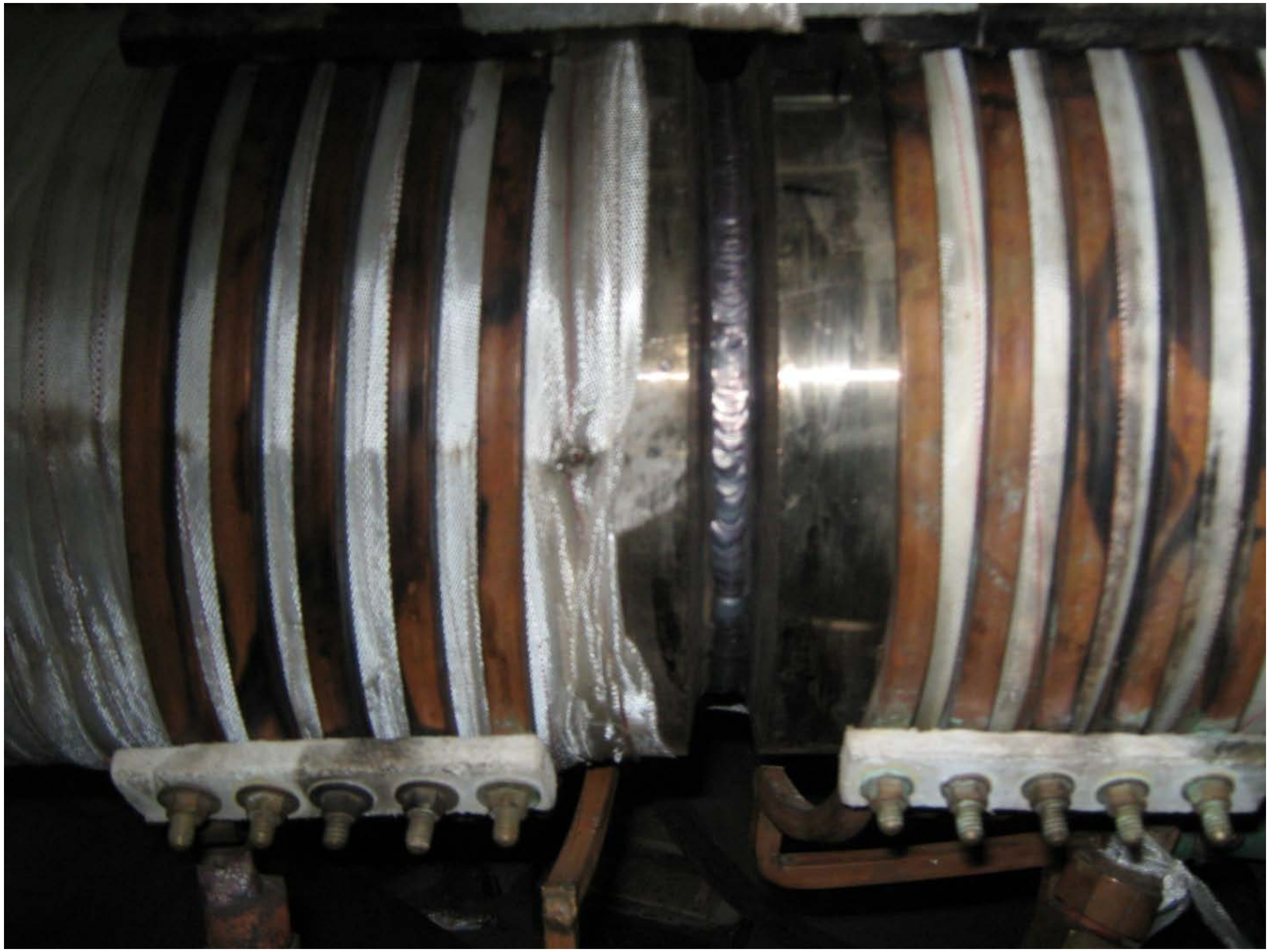
- The welding speed and welding current varied quite a bit for any electrode diameter. This may improve in the next trial welding.
- The power setting during PWHT needs to be improved in next welding trial.
- A graph is included to show the temperature variation during welding and during PWHT.
- I propose that the weld can now to be inspected by radiography, UT, LPT, then cut and the cut section can be sent to metallurgical laboratory for microstructure examination at weld zone and at HAZ.
- Cut samples may be sent to Vizag or to Mumbai laboratories for tensile test and bend test on the weld as per WPS.
- The induction heater power settings during PWHT was noted by the VEL person, but not reported to me by Mr. Rajesh of FFPL. I propose that we must get the power setting, induction power setting, frequency setting and induction current setting back from VEL operator for our interest. This I propose to get when we visit VEL next time.
- The hardness should be cross-checked at Jewel Metallochem / Metallurgical laboratory. The hardness readings recorded by Mr. Rajesh of FFPL varies quite a lot and may not be very dependable. Also, the hardness varied in two parts of the pipe, and hardness was different in the two sections after welding also.

Panel for Induction Heating System

Preheating by Induction Heating System



Preheating by Induction Heating System



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Welding in progress with Induction Heating System

Welding in progress with Induction Heating System

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Welding in progress with Induction Heating System

FLASH FORGE
Source.Design.Process.

Welding in progress with Induction Heating System

Pre heating & welding arrangement in P 91 steel

Preheating Pipe to Pipe **Fabricated Tee** by Resistance Heating Systems

PWHT Pipe to Pipe Weld by Resistance Heating Systems

P 91 Job

Tee – Reducer – Pipe – Elbow – Pipe

P 91 Job

Tee – Reducer – Pipe – Elbow – Pipe

P 91 Job

Tee – Reducer – Pipe – Elbow – Pipe

P 91 Job

Tee – Reducer – Pipe – Elbow – Pipe

FLASH FORGE
Source.Design.Process.

Fabricated Pipe to Pipe Tee

Fabricated Pipe to Pipe Tee

Fabricated Pipe to Pipe Tee

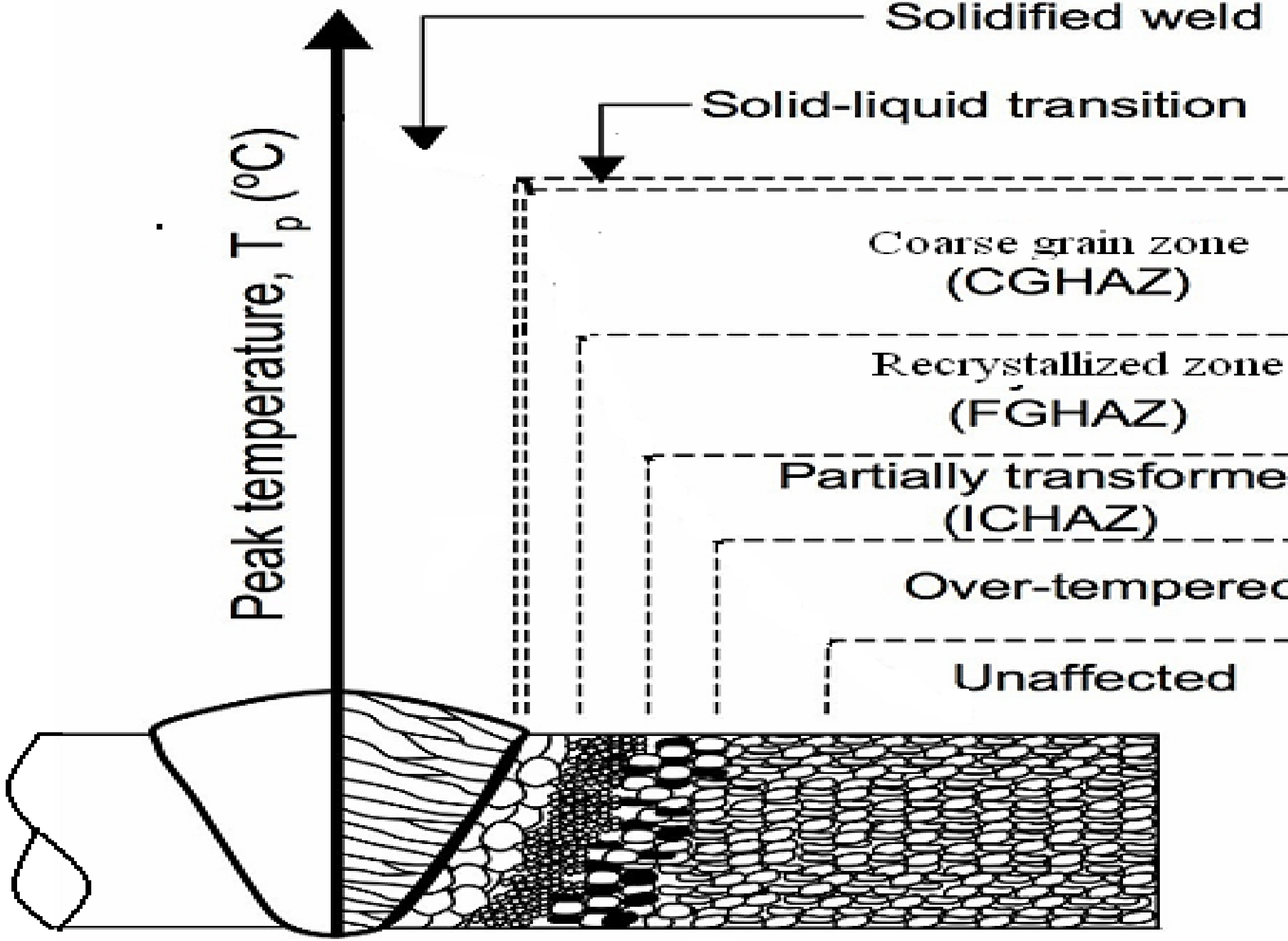
Weld Microstructures

Composition, diffusion kinetics in heating, & forging cause carbo-nitride precipitation in microstructure and control creep strength.

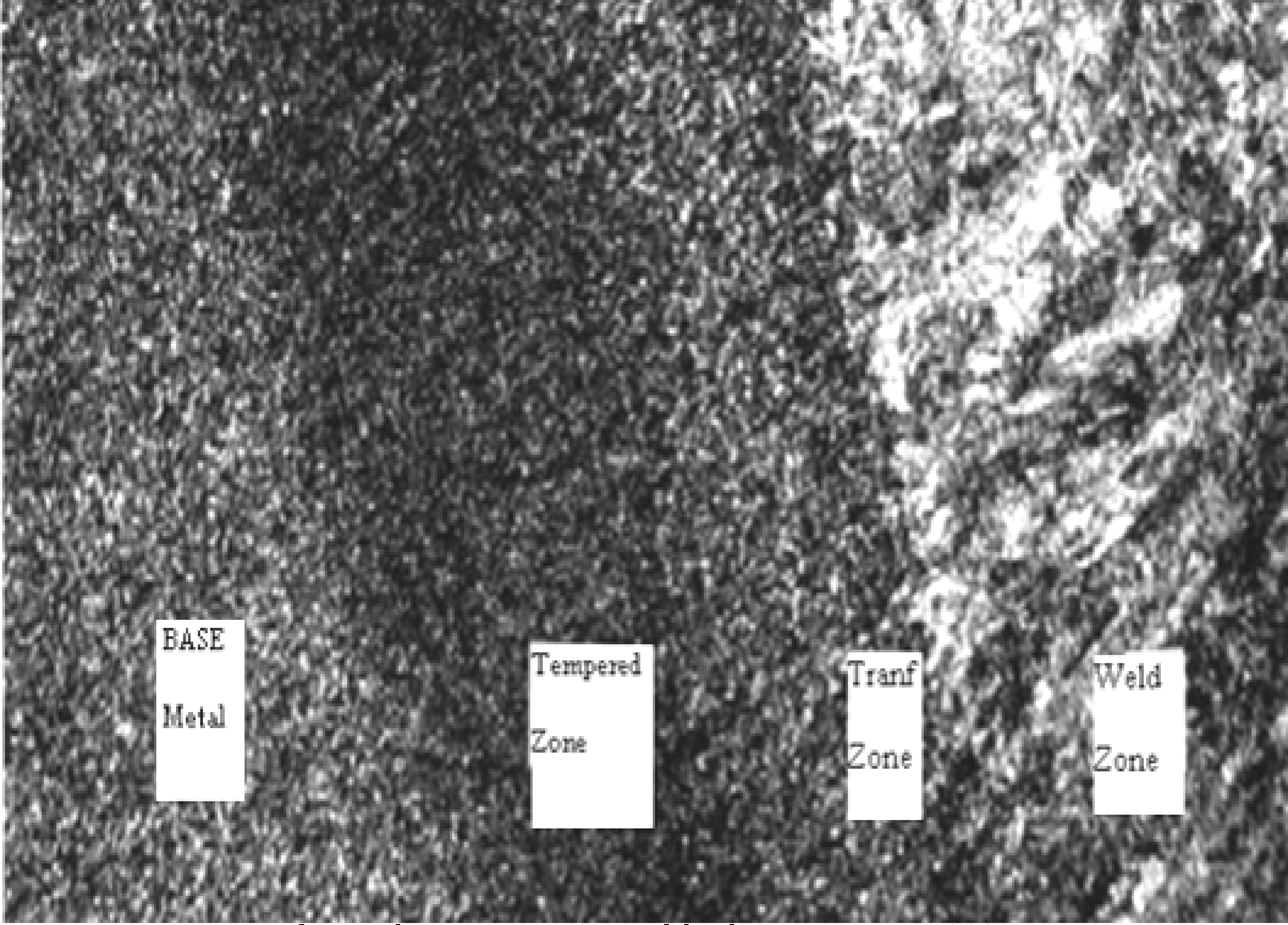
Improper microstructure can cause a shift away from desired tempered martensite, and impair mechanical properties of the alloy.

Microstructures with heat treatment conditions are exhibited in our slides.

P 91 plate weldment, 50 mm thick. 2X



Solidified weld
Solid-liquid transition
Coarse grain zone
(CGHAZ)
Recrystallized zone
(FGHAZ)
Partially transforme
(ICHAZ)
Over-temperec
Unaffected
Peak temperature, T_p (^oC)



Trans Zone:- transformation zone; P 91 weld microstructure, 200X

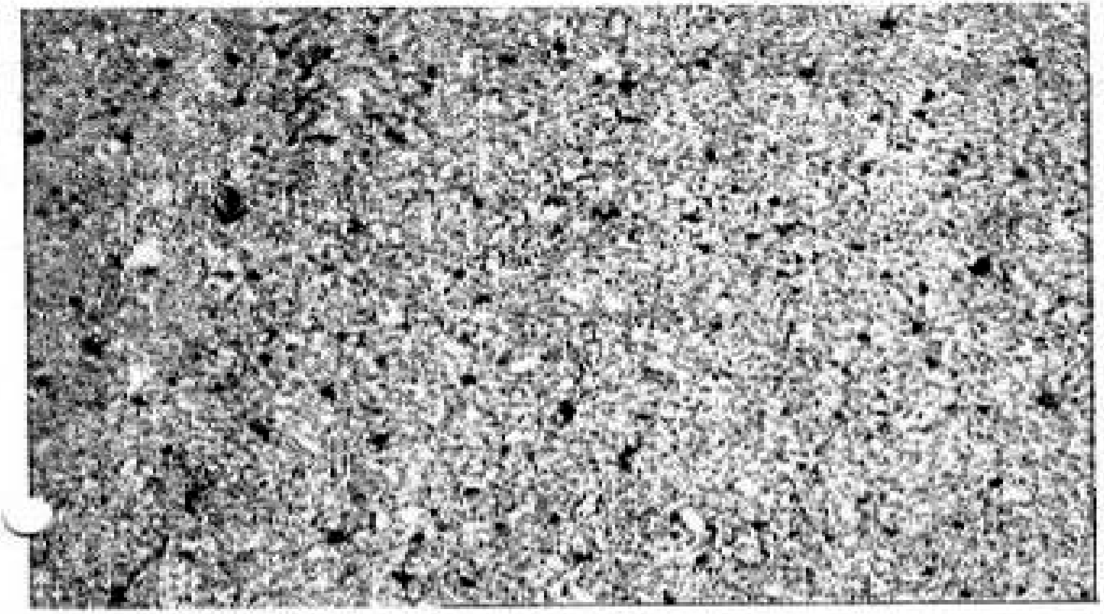
Jewel Metallochem Laboratory Pvt Ltd.

A-12, Ghatkopar Industrial Estate, Off LBS Marg, Ghatkopar (W).

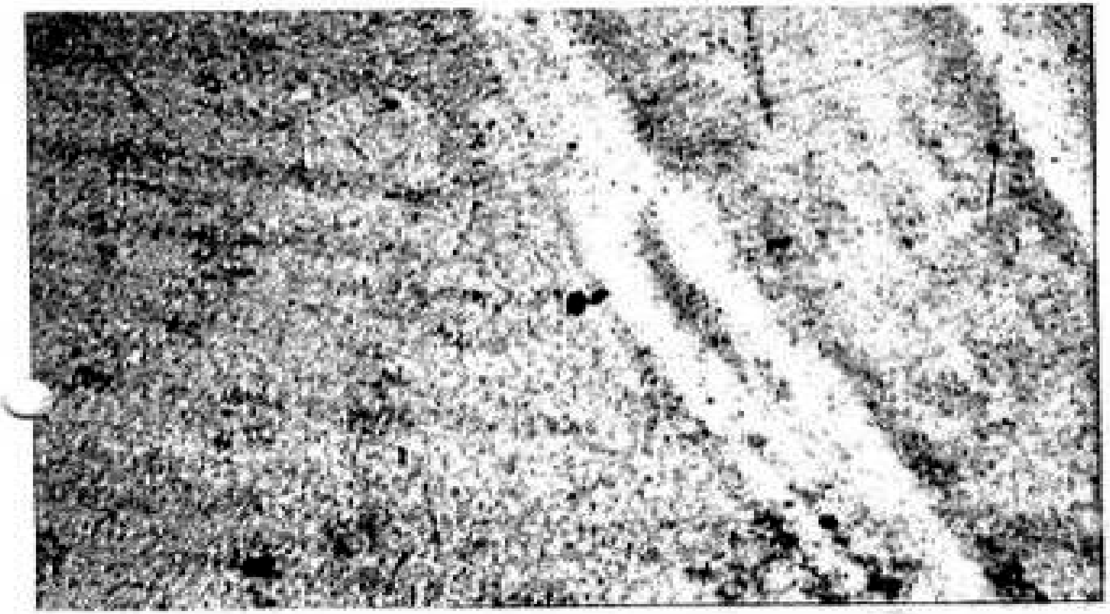
Lab ref No.	F 73174
ID No.	01
Etchant	Nital
Magnification	750 X
Description	Structure consisted of tempered bainite

Jewel Metallochem Laboratory Pvt Ltd.

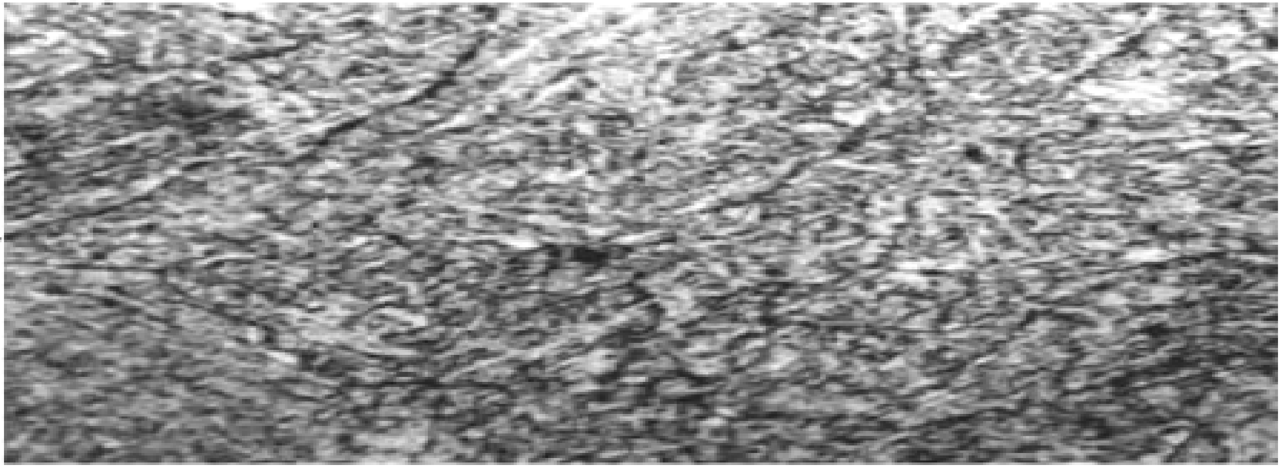
A-12, Ghatkopar Industrial Estate, Off LBS Marg, Ghatkopar (W).



Lab ref No.	F 73543
ID No.	HAZ - 1
Etchant	Nital
Magnification	100 X
Description	Structure consised of carbides disperesed in ferrite matrix.



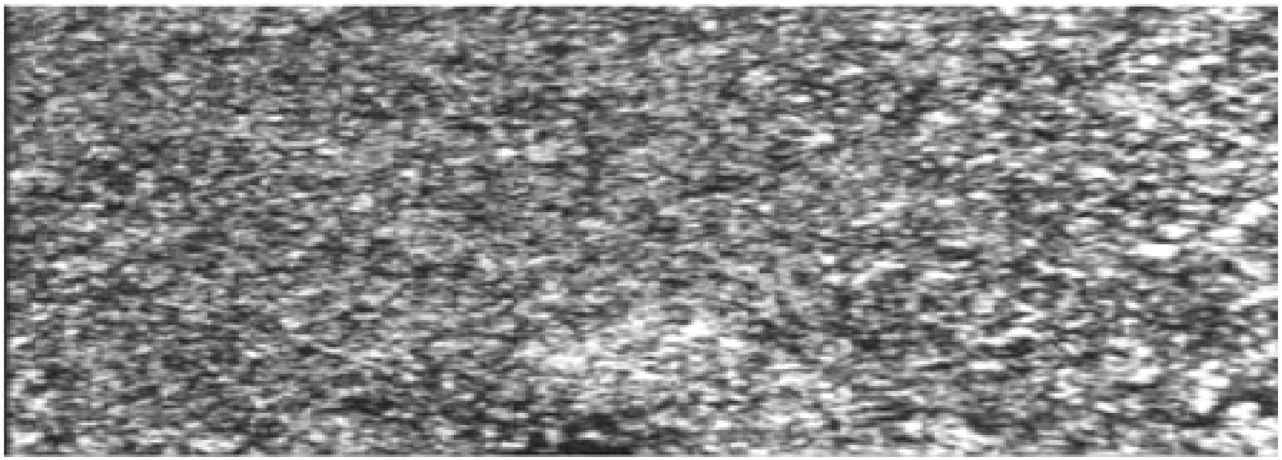
Lab ref No.	F 73545
ID No.	WZ
Etchant	Nital
Magnification	100 X
Description	Weld microstructure



CGHAZ

Coarse grain Zone

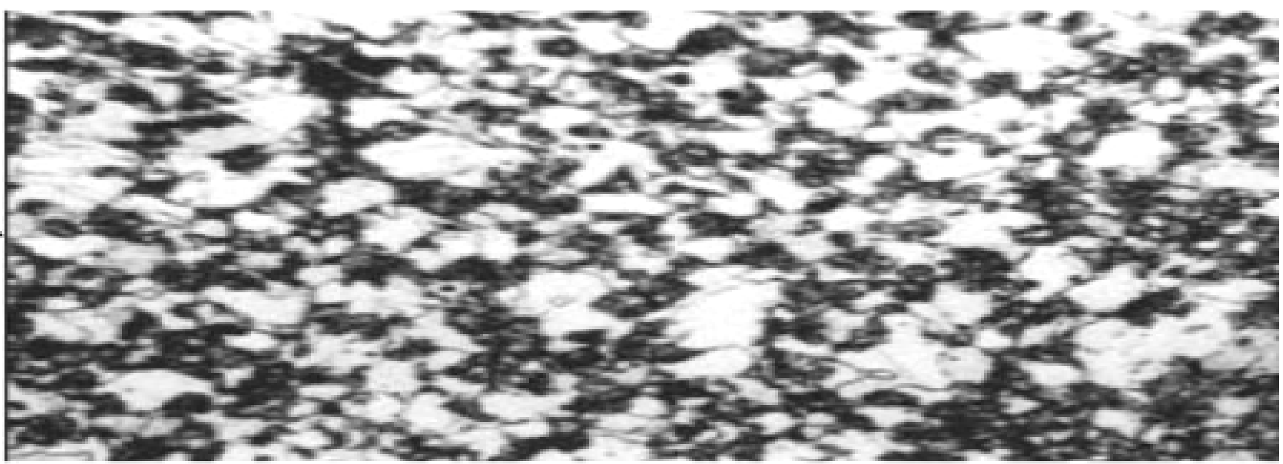
Micro-4, 100X



FGHAZ

Fine grain zone

Micro-5, 100X

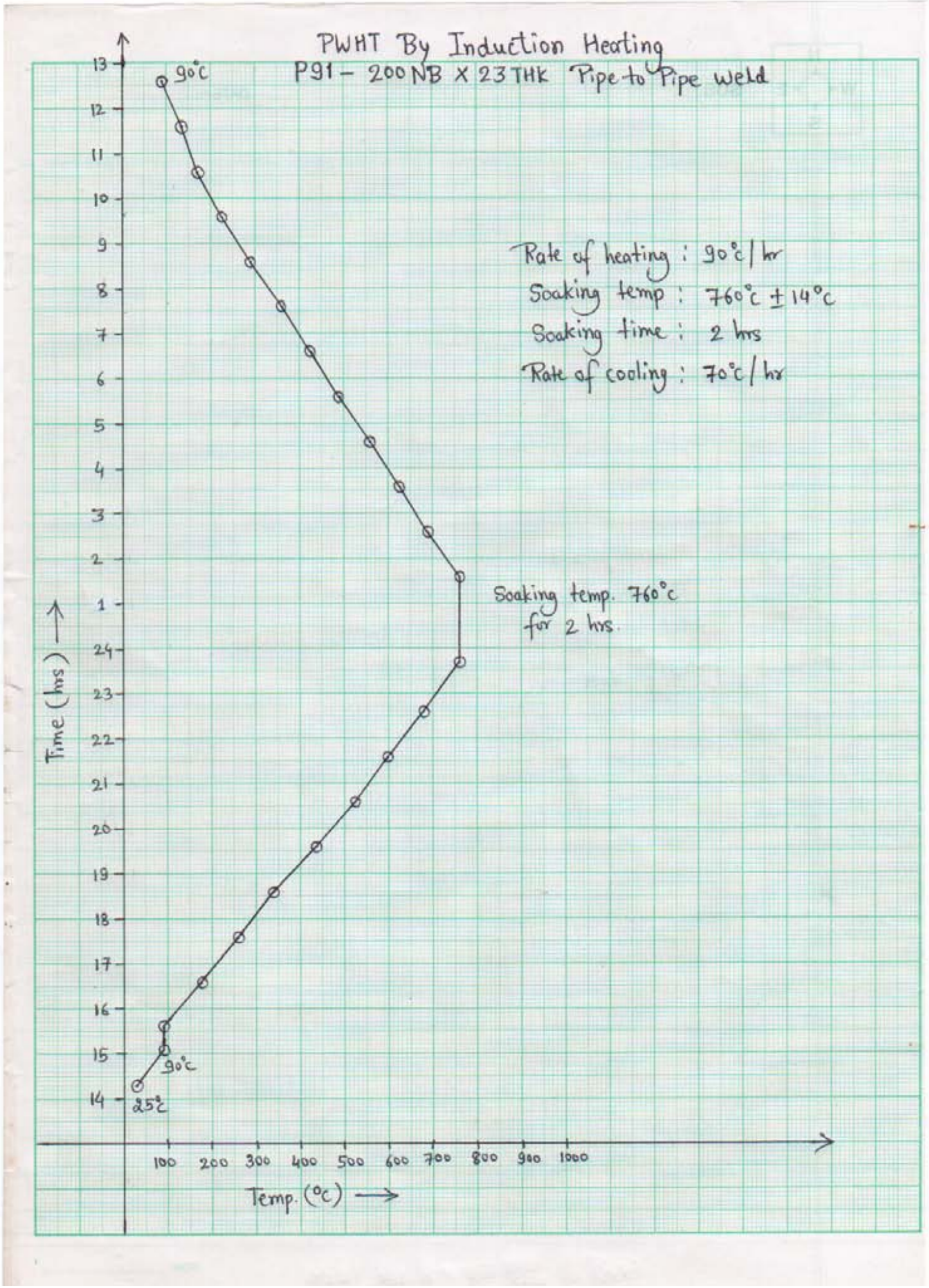


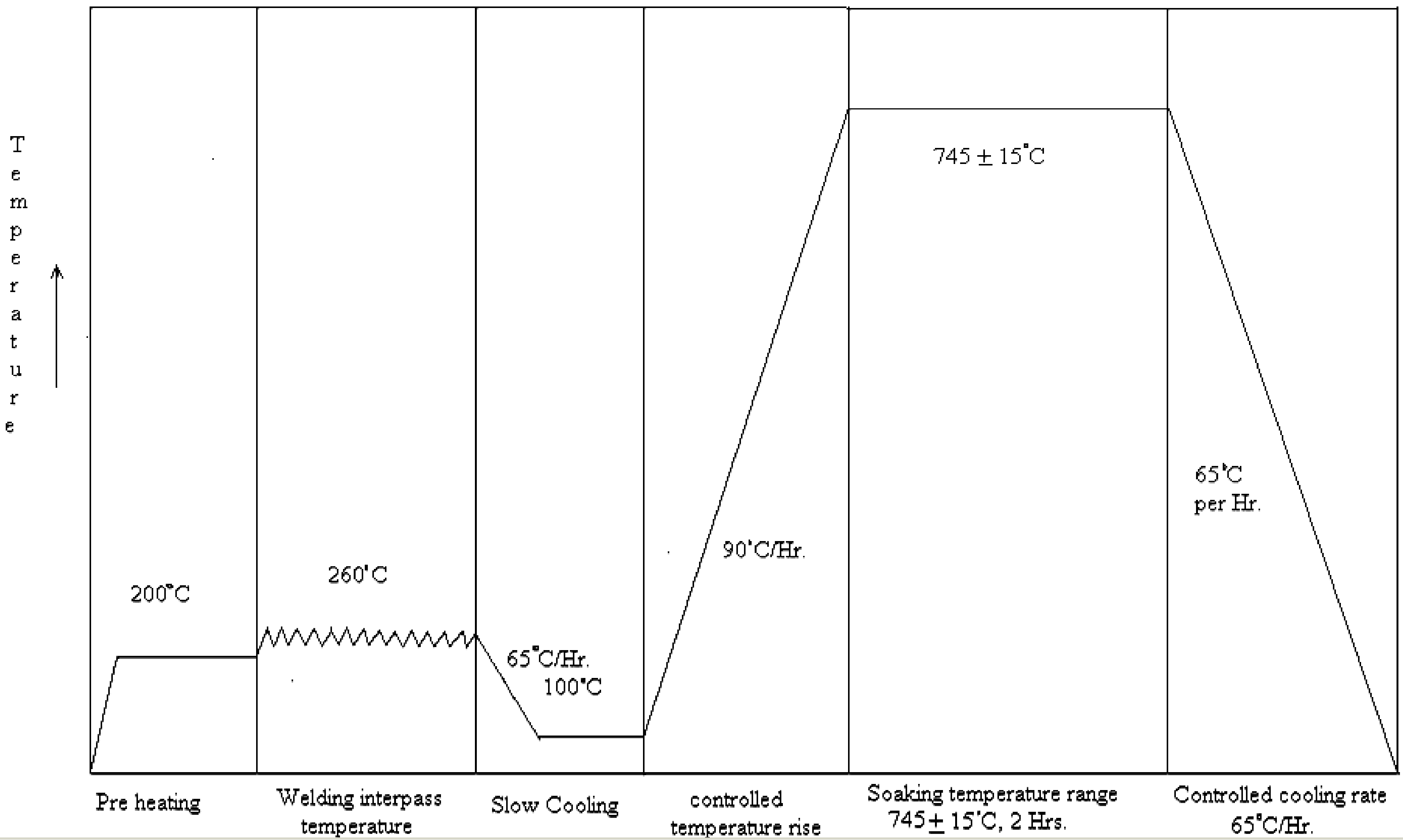
ICHAZ

Inter critical
Partially transformed

Micro-6, 100X

Graph for PWHT





Heating schedule for P 91 weld in PWHT

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Input heat control in welding

The welding procedure clearly specifies various welding inputs as criteria i.e. preheat, interpass temperature, and PWHT temperature. The key to these control areas are use of preheating by:

a. Resistance heating,
b. Induction heating.

Preheating by gas is to be avoided as results in non-uniform temperature distribution and unpredictable properties.

Temperature control is necessary to produce desirable microstructure and hardness.

Induction heating offers advantages as it can have good depth of penetration in work piece and the individual atoms/ molecules of the job are excited by induction heating, making it a faster and better heating process.

At FFPL, we check integrity of welding by radiography, U.T., tensile strength, impact strength, bend test, and creep rupture strength test.

The performance of Grade 91 welds also depends on having the correct chemical analysis in the weld metal and both base metal and filler metals be checked for chemistry prior to welding.

Conclusion on P91 fabrication

1. The base metal (P 91) offer superior properties, but restoration of weld heat affected zones (HAZ) or remediation of cold work / bending effects have to be fully examined.
2. For the CSEF steels, proper preheat and PWHT are not optional, but they are mandatory.
3. Greater attention to weld filler wire selection, strict heat-treatment schedules are the reasons that the CSEF alloys must be treated differently to obtain weld integrity and service life.
4. The mechanical properties of P 91 are superior to P11 or P22, but the properties of grade P 91 steel depend on the selection of:

(a) Judicious selection of raw material, forging conditions, matching of chemical composition of welding consumables and base metal, and hydrogen control are required.

(b) Creation of tempered martensitic microstructure by a suitable heat treatment, and maintenance of this microstructure throughout its service life.

(c) Modern techniques of induction heating offers better control of temperature distribution and depth of penetration in weldment.

BACK

ELECTRIC POWER RESEARCH INSTITUTE

Service Experience for Grade 91 Steel in Boilers and Piping

Jonathan Parker

Structural Integrity Associates, Inc

VGB Workshop
Materials and Quality Assurance
Copenhagen, May 13 – 15 2009

Structural Integrity Associates, Inc.

INTRODUCTION

- Illustration of Problems with Grade 91 steels
  - Design / Operation
  - Fabrication
  - Welding
  - Construction
  - Material Quality and Processing
- Illustration of Life Management Solutions
  - Better Understanding of Factors Affecting Performance
  - Better Methods for Quality Assurance
- Life Management Program
  - Integration of Analysis, Instrumentation and Inspection

ILLUSTRATION OF PROBLEMS

- Design / Operation
  - Allowable Stresses
  - Efficiency Factors
  - Reinforcement / Geometry transitions
- Fabrication
  - Forged / cast / welded
  - Defining Process parameters
  - Controlling Process parameters
  - QA

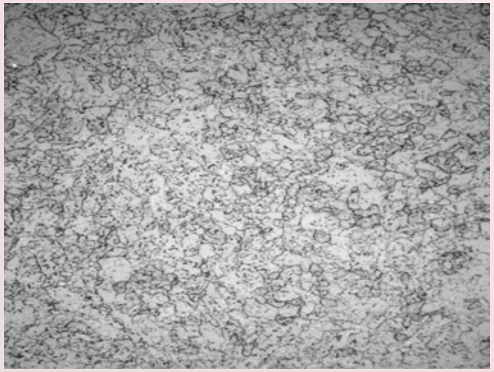


ILLUSTRATION OF PROBLEMS

- Welding
  - Process / Consumables
  - Girth Welds
  - Seam Welds
  - Post Weld Heat Treatment – subcritical or Renormalization

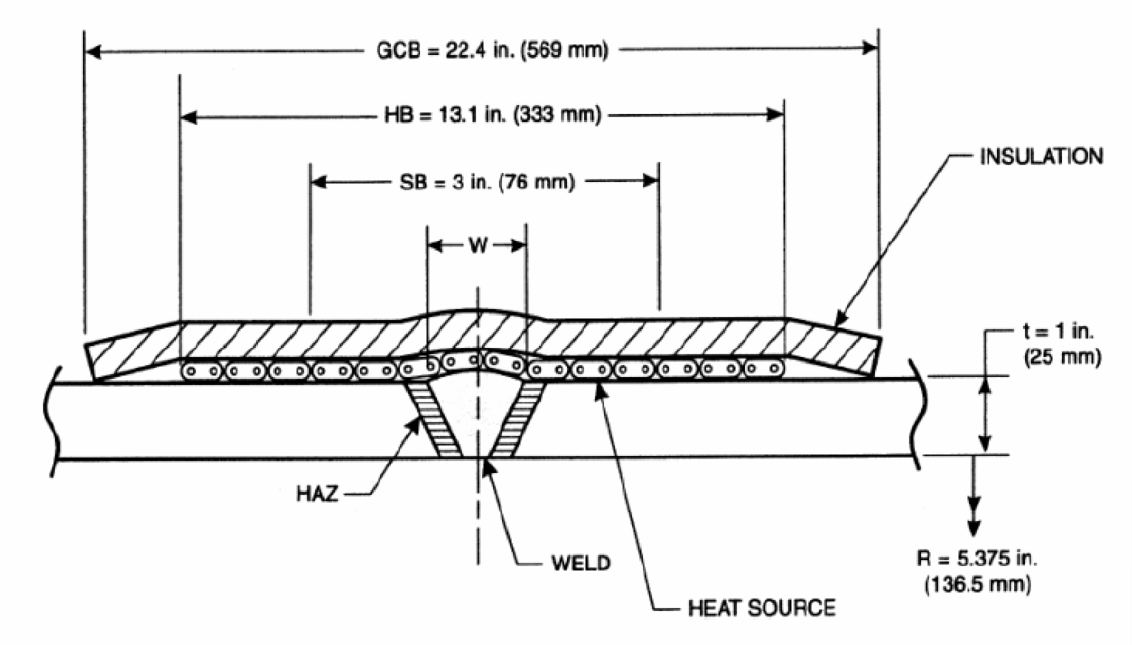
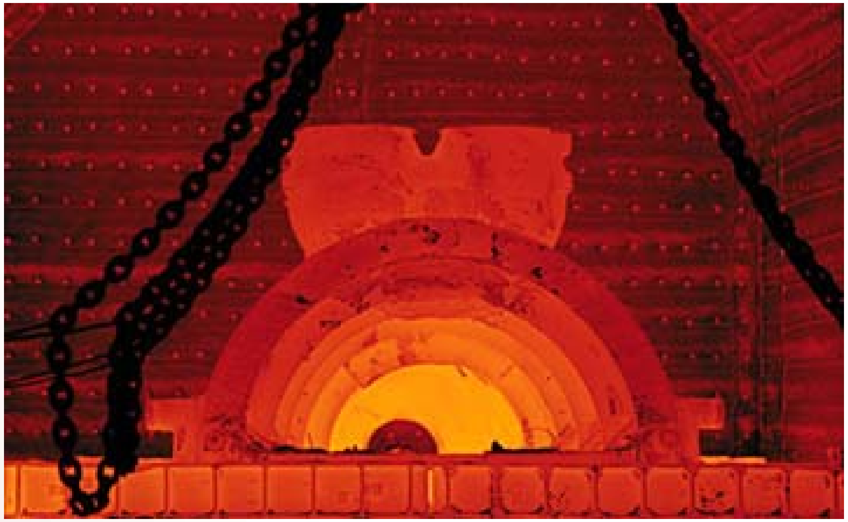


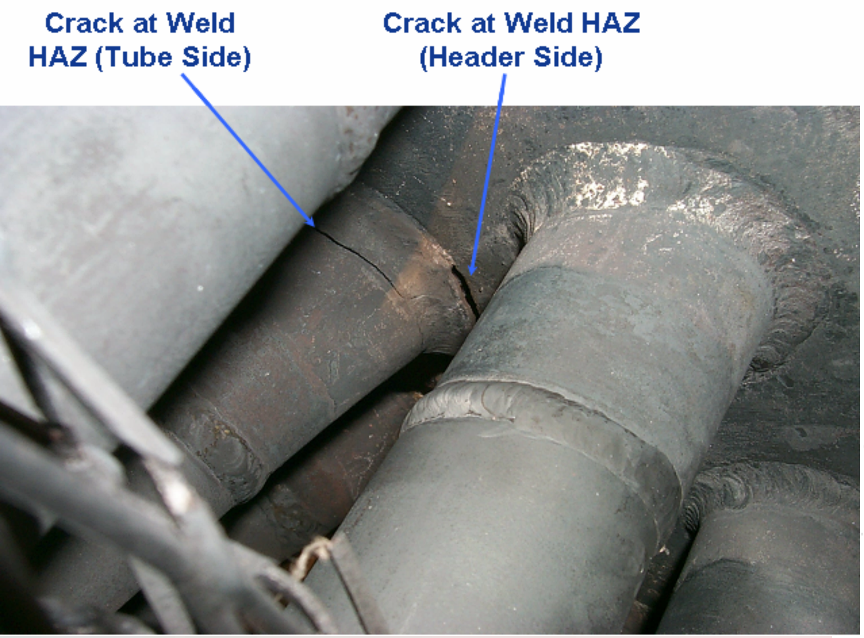
ILLUSTRATION OF PROBLEMS

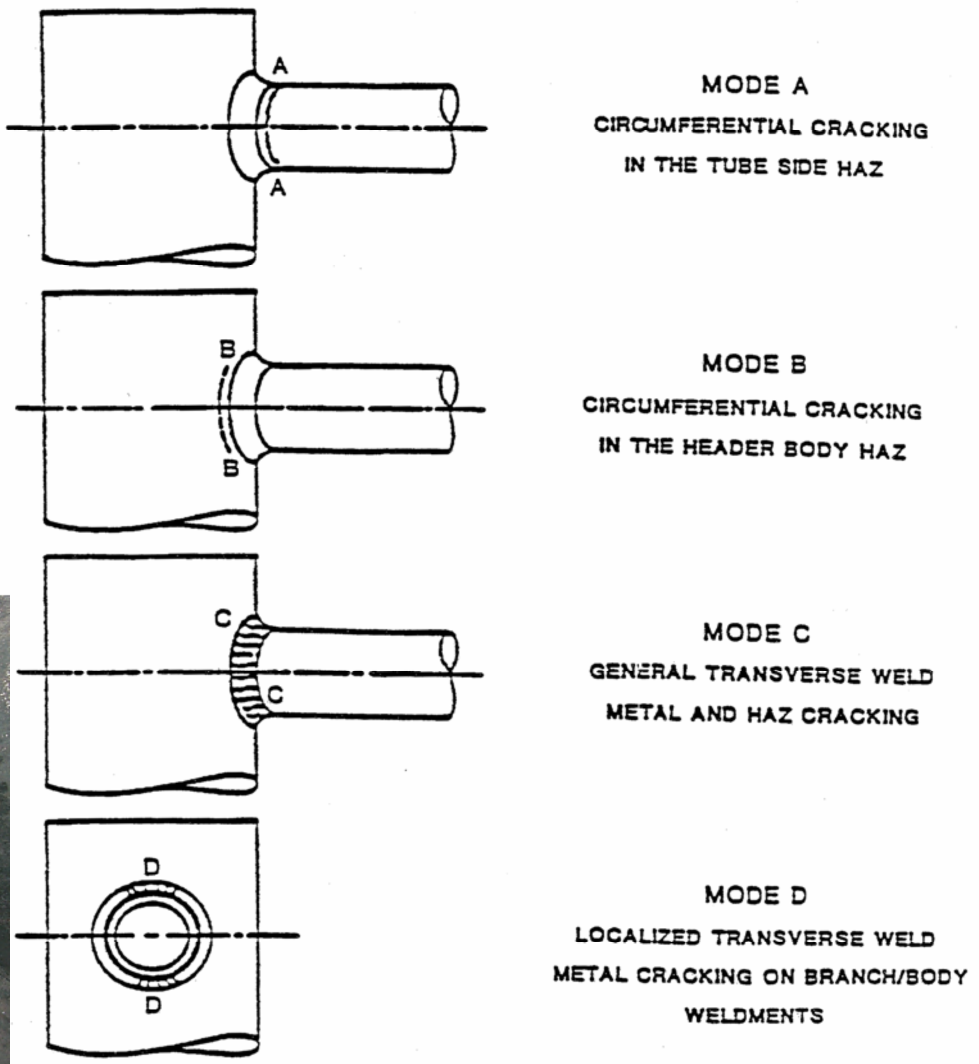
- Construction
  - Post Weld Heat treatment
  - Field handling and Installation
  - Cold Spring
- Material Quality and Processing
  - Composition
  - Normalizing
  - Tempering



DESIGN TYPE

- Connections,
- e.g. Headers, Tees, etc





Fittings in Piping Systems

Potential Problems following Fabrication

Wrong

- **Weld Metal**
- **Heat treatment of parent**
- **Heat treatment of Welds**

Fittings in Piping Systems - Reinforcement

- Cracked 18"x14" weldolet in the hot reheat system. Creep cavitation initiated in the Type IV region of the heat affected zone and propagated into the base metal.

Fittings in Piping Systems

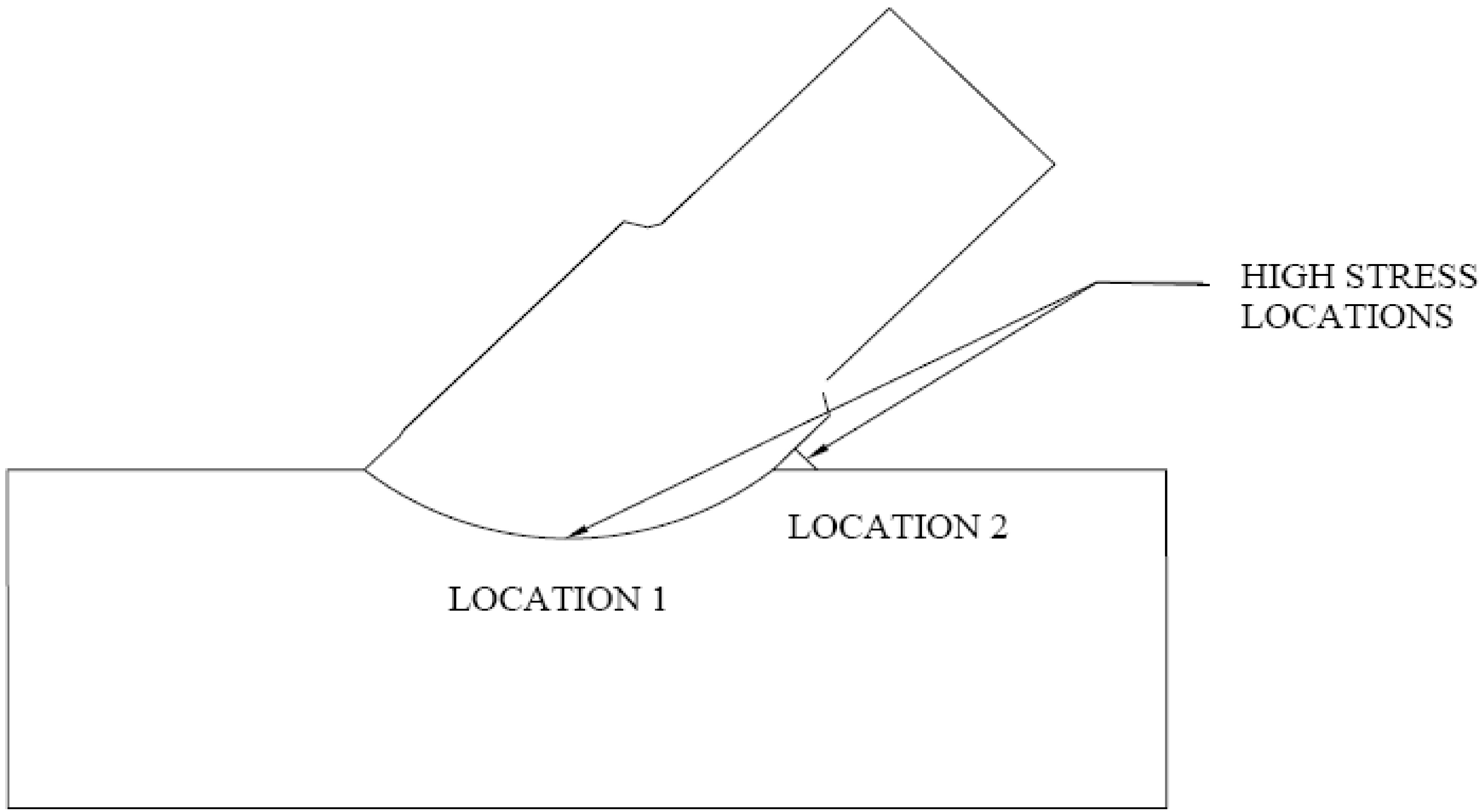


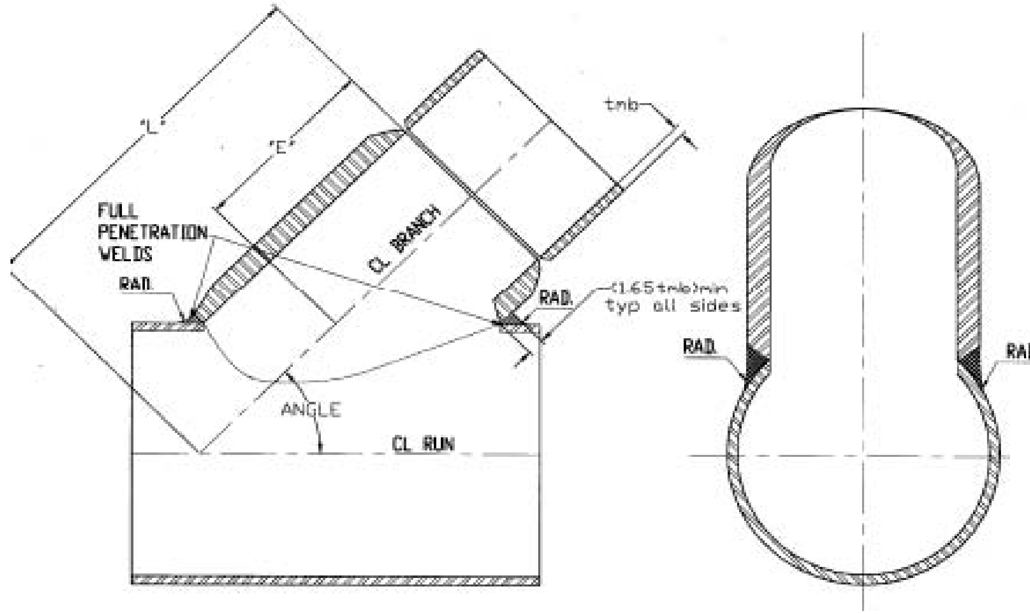
Fig. 3: High Stress Areas/Locations of Potential Cracking

Fittings in Piping Systems

Fig. 4: Recommended replacement fitting--one-piece fully contoured lateral

Fittings in Piping Systems

Fittings in Piping Systems

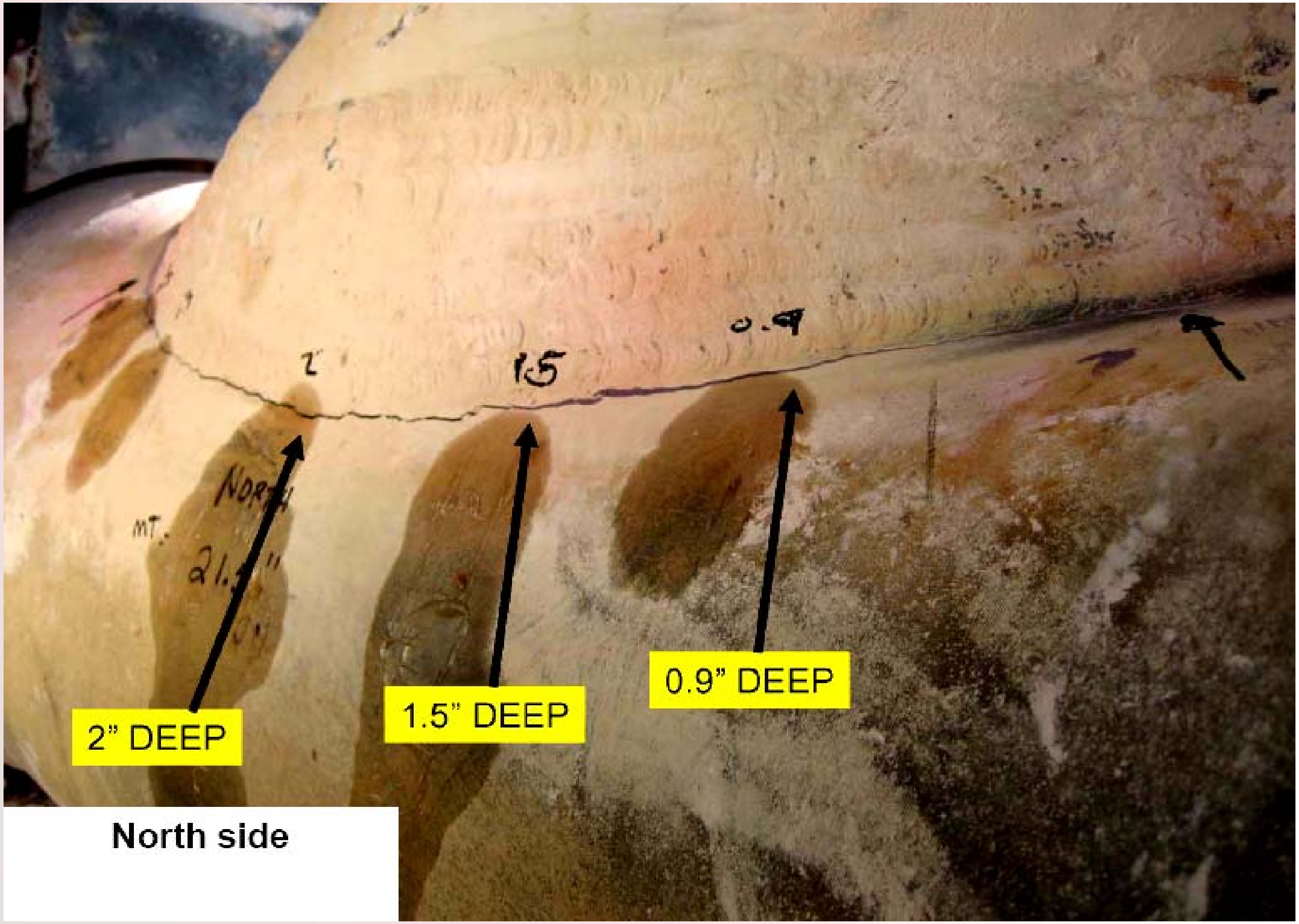


Weld-On Design

- Typically designed using area replacement rules
- Results in wall thickness mismatch between fitting and header
- Approach may not be sufficient for large branch to header diameter ratios

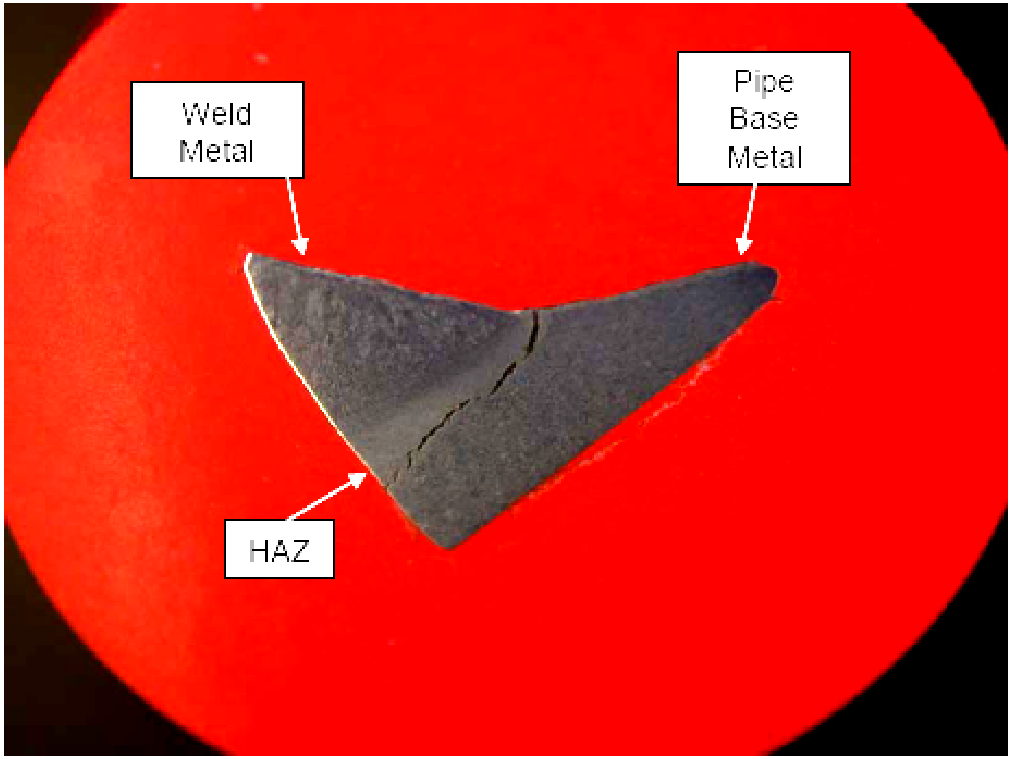
Fittings in Piping Systems

Fittings in Piping Systems



Fittings in Piping Systems

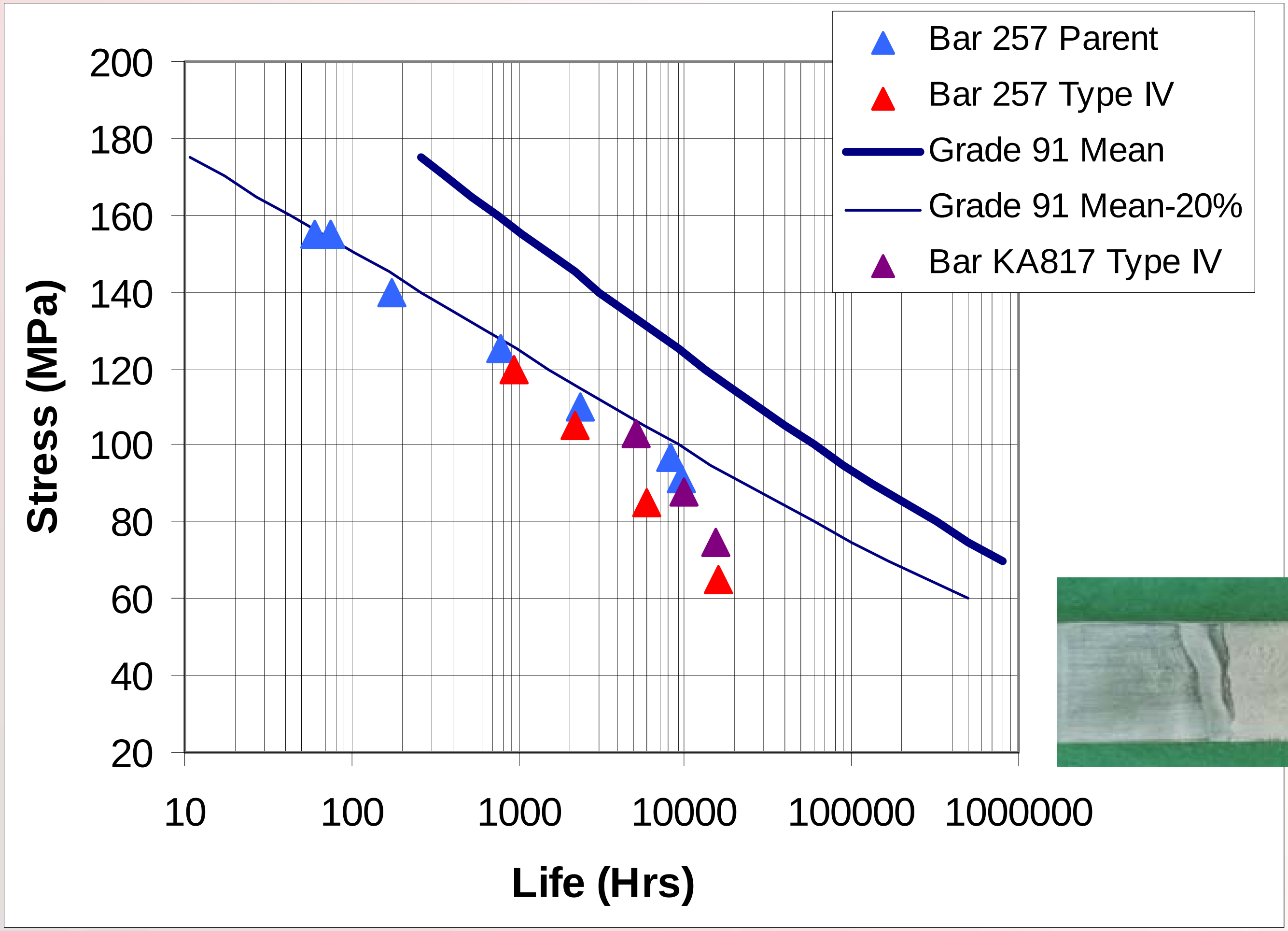
MS Lateral – Boat Sample (Cracks in Type IV HAZ)



Weld Metal	273-280 BHN
HAZ	217-267 BHN
Base Metal	211-218 BHN

Weld Performance

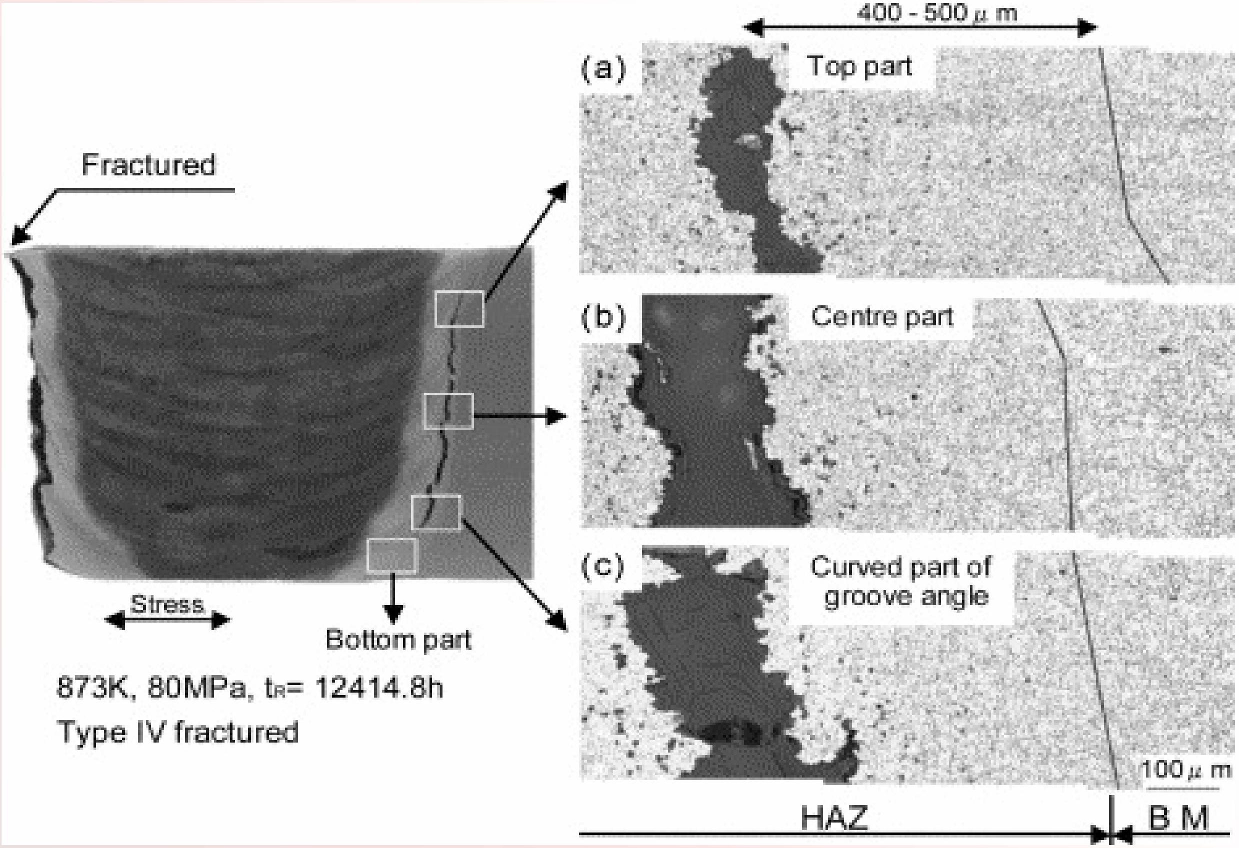
Type IV cracking in service in less than 10 years operation



Based on Brett 2007

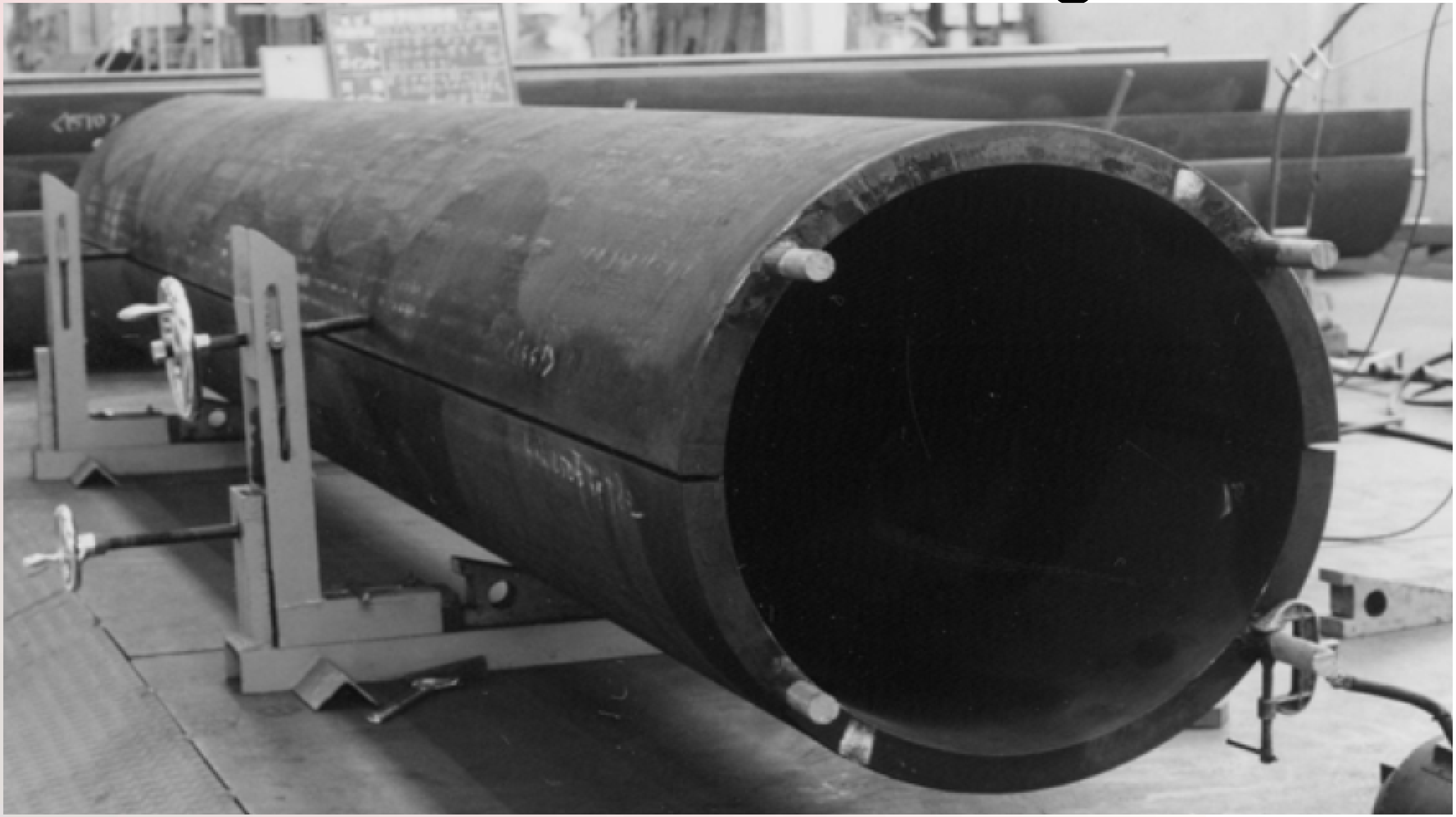
Weld Performance

Laboratory testing can reproduce service Type IV cracking

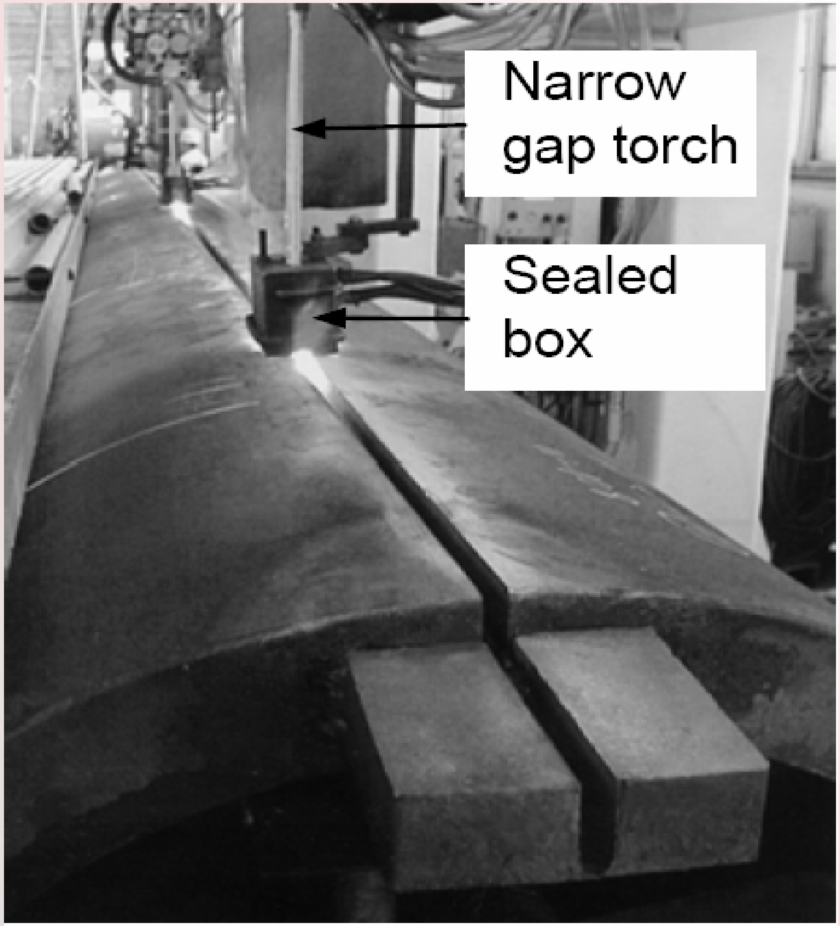


Watanabe et al, 2006

Weld Performance – Long Seams



Weld Performance – Long Seams



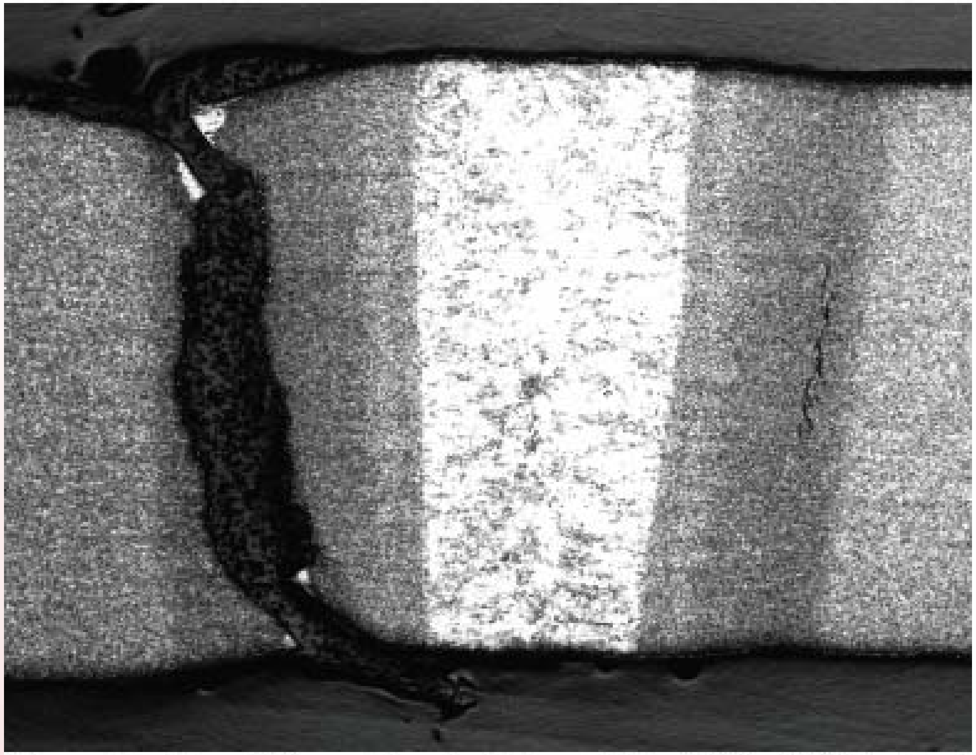
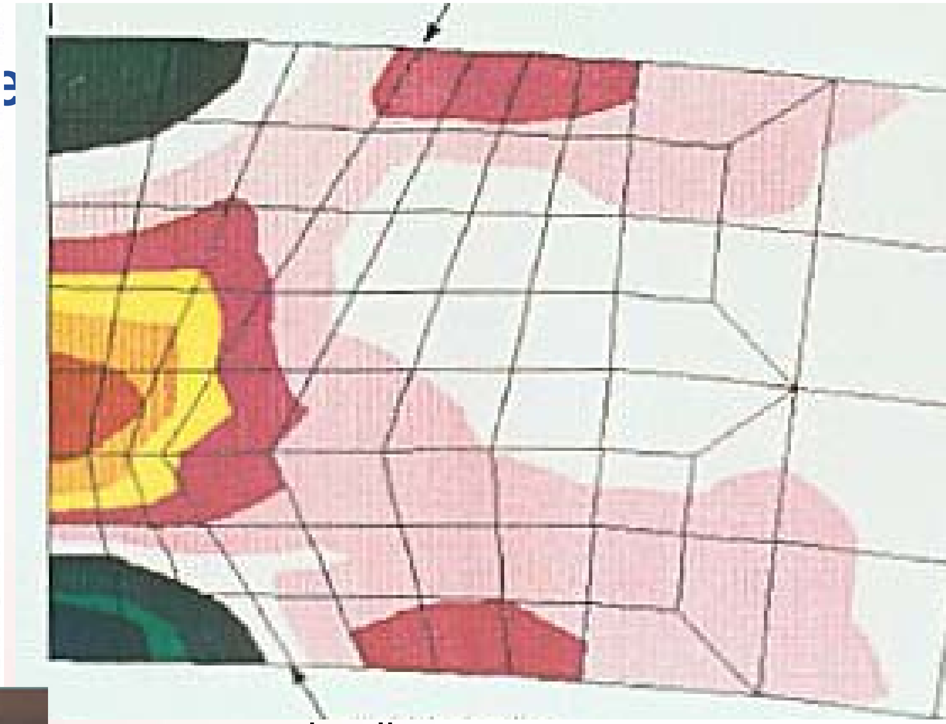


Figure 5: Type IV cracking in EB welded 9%Cr 1%Mo steel

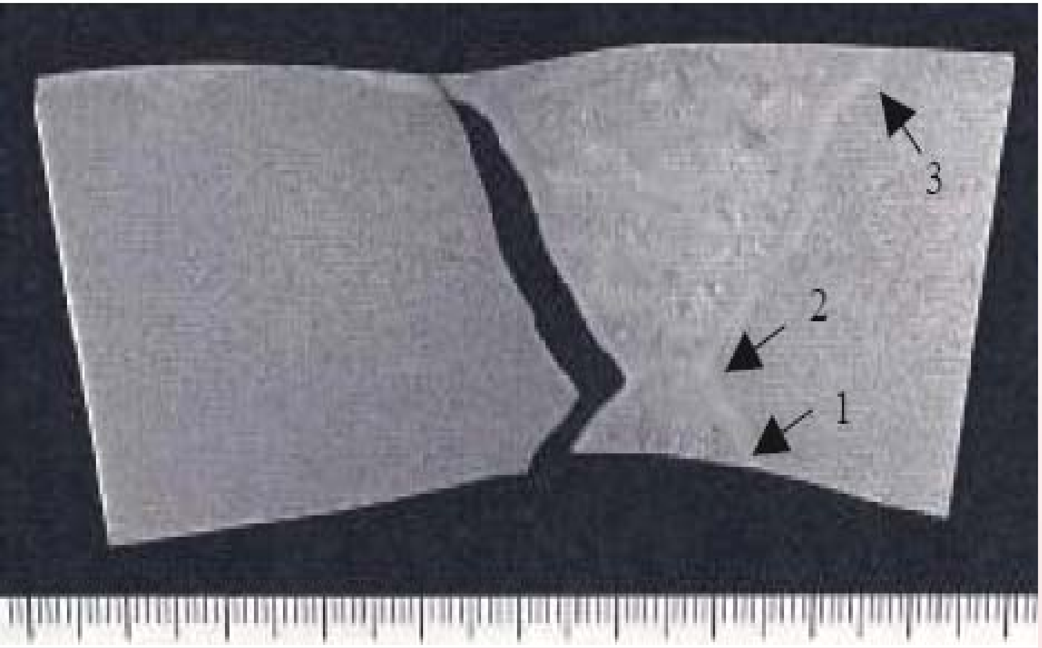
Weld Performance – Long Seams

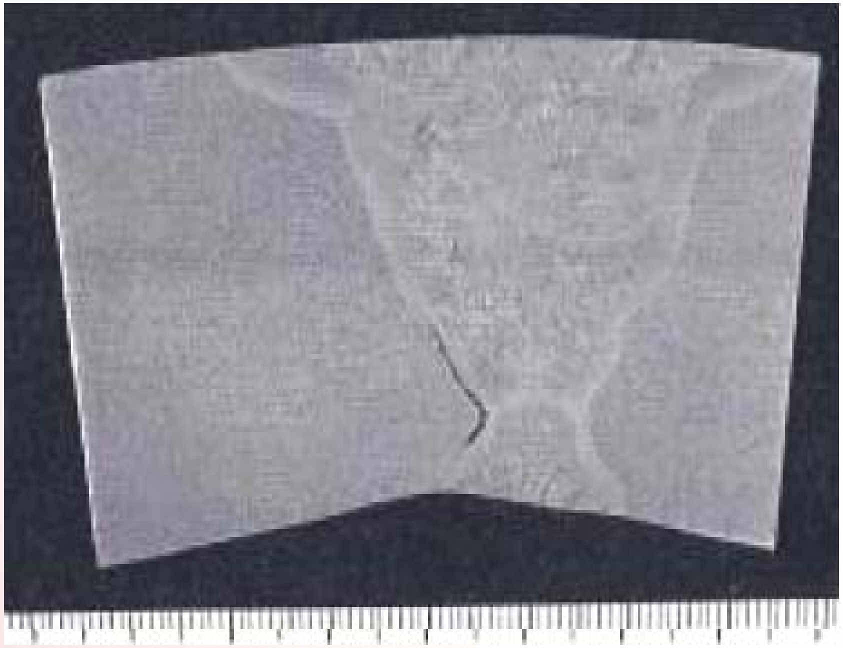


Fusion line

Weld Performance – Long Seams

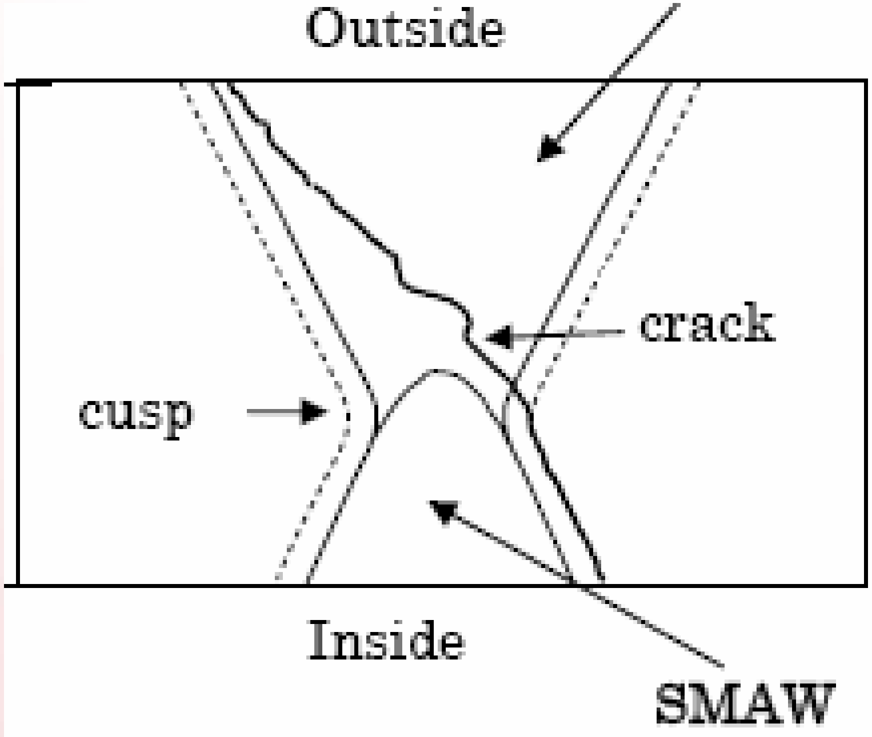
Cracking has been found in Grade 91 seam welded components





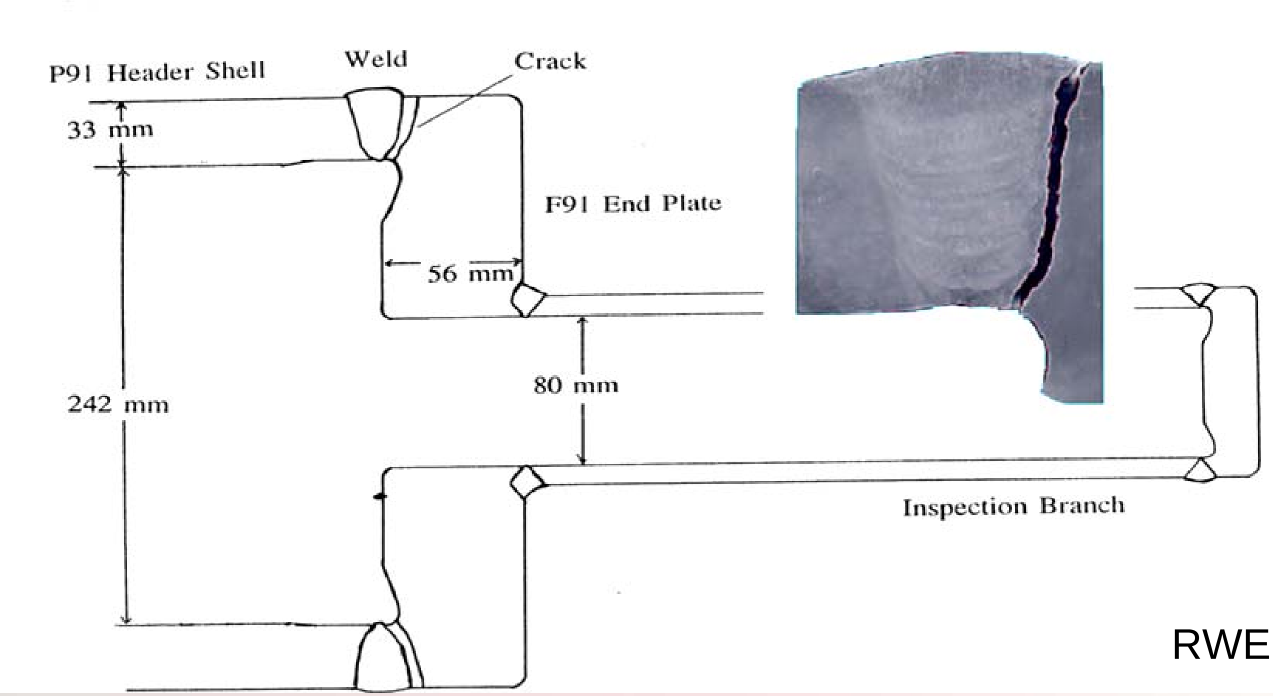
Weld Performance – Long Seams

Cracking has been found in Grade 91 seam welded components



Weld Performance

End cap geometry causes an additional bending stress which acts across the intercritical region of the weld HAZ (weak), Because the enhancement is geometrically induced the risk of damage is elevated equally around the weld.



RWE innogy

Weld Performance

Similar damage in a different example of service cracking

Weld Performance

Many Complexities because Service Performance depends on local Properties of the constituents.

These are Affected by
- the composition, different Thermal Cycles, and
- the size of different zones, and
- the operating regimes of stress and temperature

Weld efficiency factors now widely applied

Challenge to maintain PWHT within defined limits

Uncertainty remains over benefit of renormalization

SHORT TERM DAMAGE

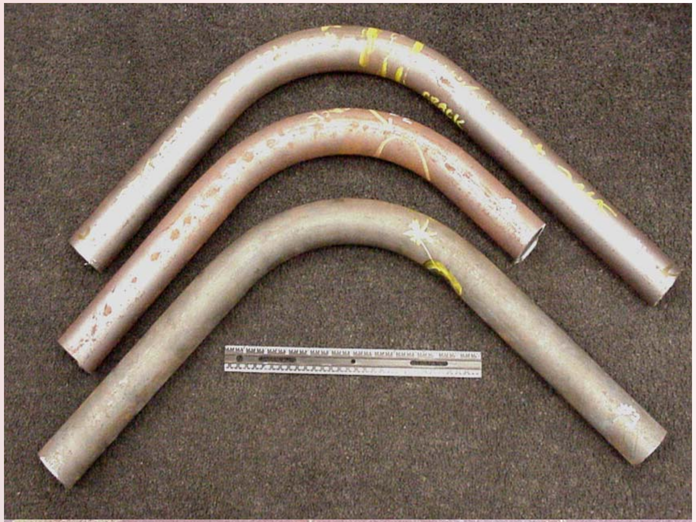
Damage found before service and early in life

Examples of mechanisms

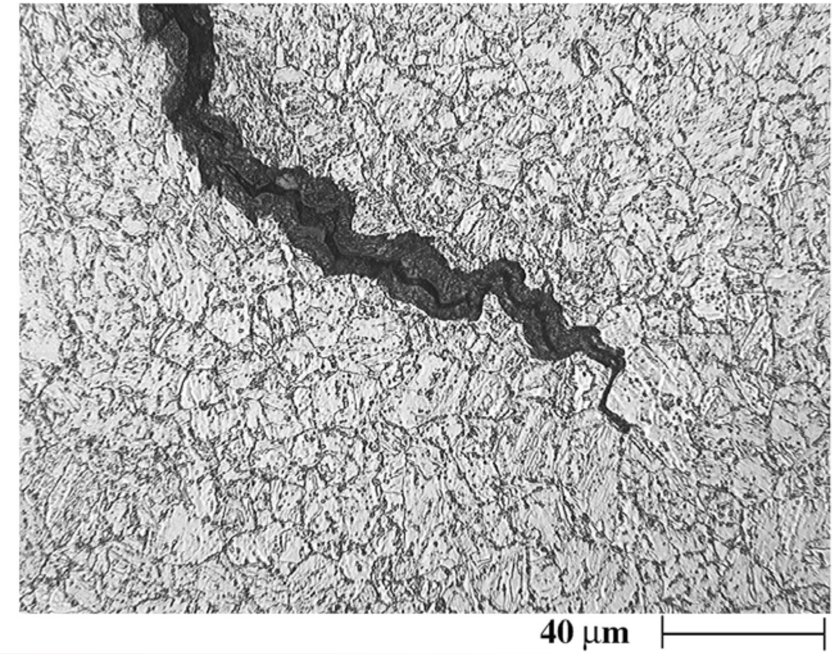
- Stress Corrosion and Hydrogen cracking
- Fabrication Related cracking and low creep strength
- Design / Operation related creep and/or fatigue

Different Root Causes, many times a range of factors involved

SHORT TERM DAMAGE



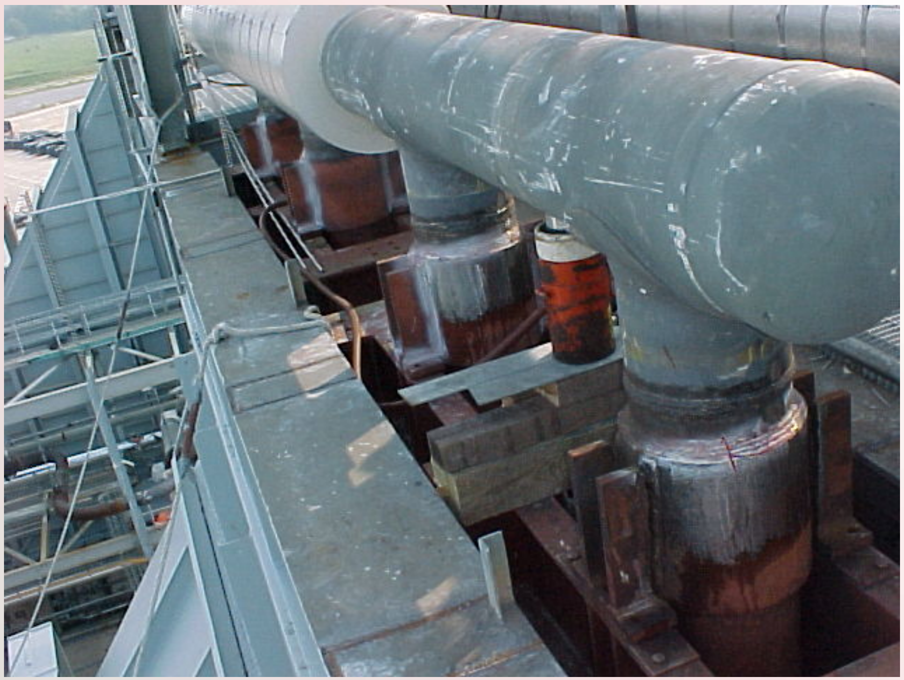
Problems of cracking, prior to, or very soon after start of service with Grade 91 tube bends, identified as stress corrosion cracking,



Pictures Alstom

SHORT TERM DAMAGE

Cracking of Steam-Cooled Component Supports (No service hours)



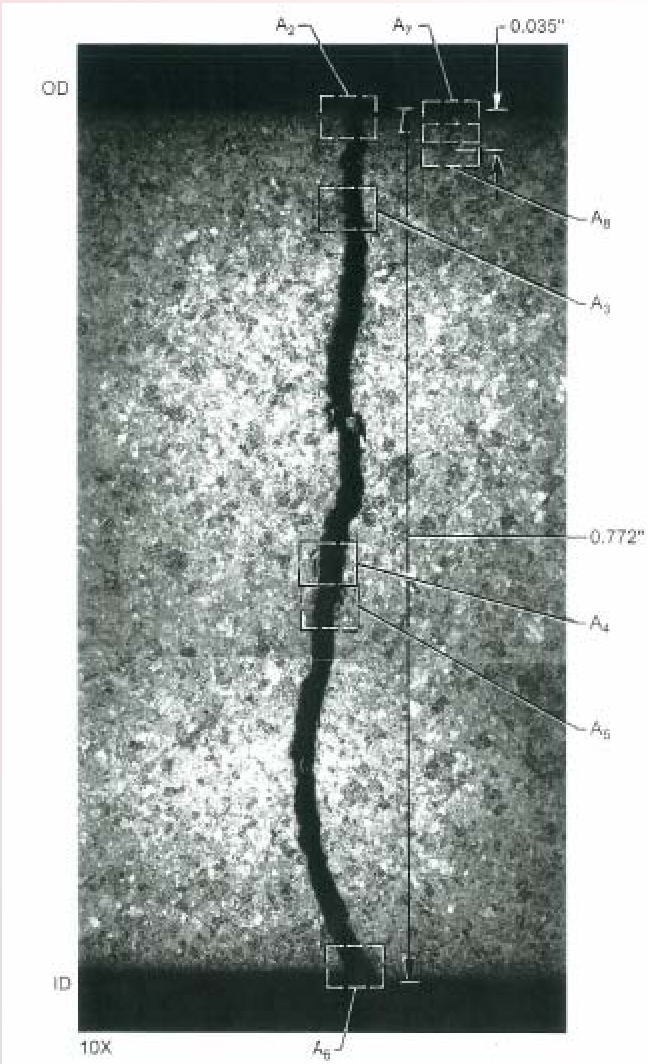
Paint found on the fracture surface

Pictures Alstom

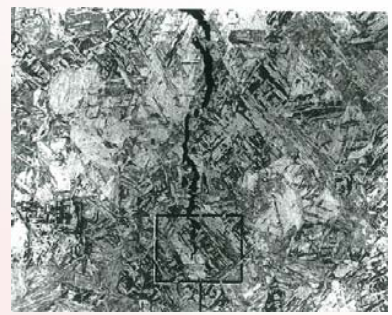
SHORT TERM DAMAGE

Grade 91 Pipe section leaked during Initial Fill for Hydro Test. Leak adjacent to but not linked to a weld. Appears to be related to lack of control during PWHT.

SHORT TERM DAMAGE



At position of apparent Crack Start, untempered martensite with a hardness in Center of wall 376 Hv

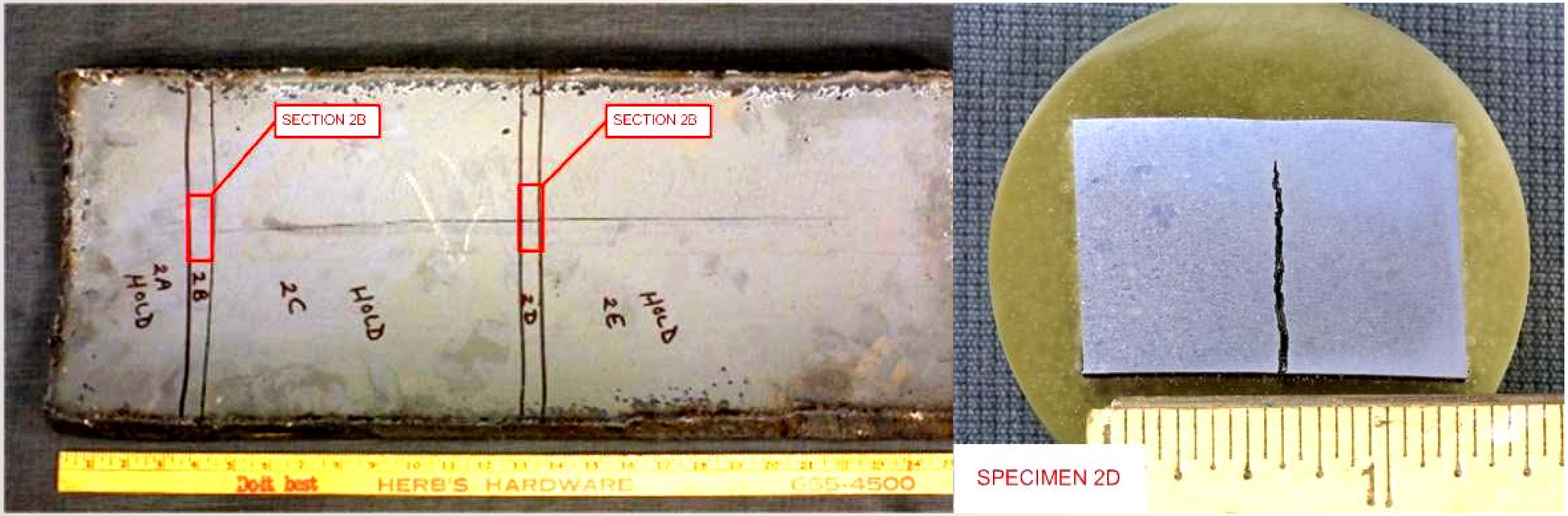


SHORT TERM DAMAGE

Leak in pipe spool repaired during forced outage with short term weld fix

SHORT TERM DAMAGE

When the pipe section was removed to allow a long term repair a second defect was found, approximately 80% through wall. Apparently no microstructural anomalies.



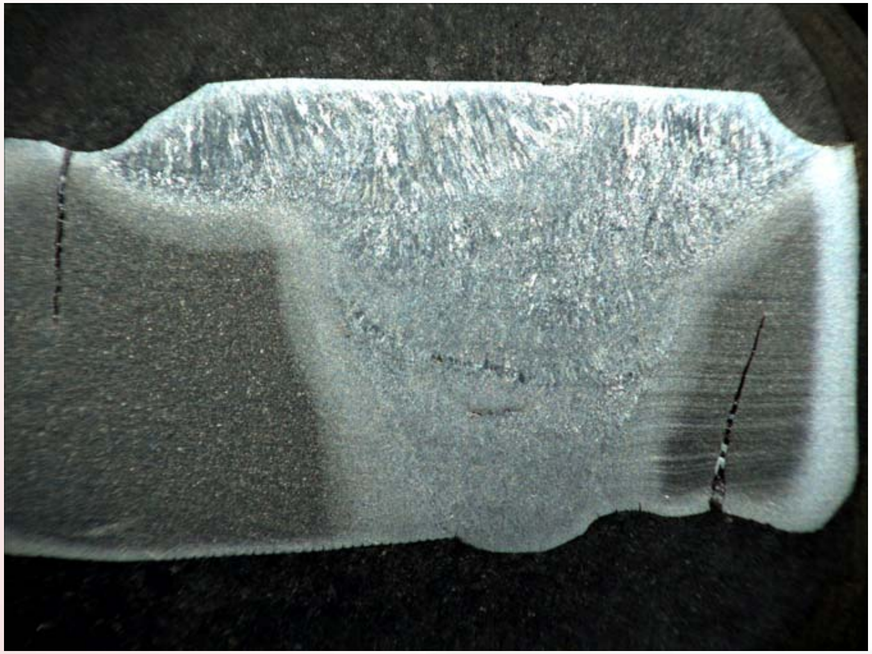
SHORT TERM DAMAGE

Attachments are frequently welded to piping components to assist with erecting systems. Cracking frequently occurs because of insufficient care

SHORT TERM DAMAGE

Unusual spray patterns from attemperator resulted in cracking. Thermal cycling due to use of attemperators & trapped condensate has resulted in damage in many HRSGs.

Design improvements BUT many components now in a state of uncertain damage

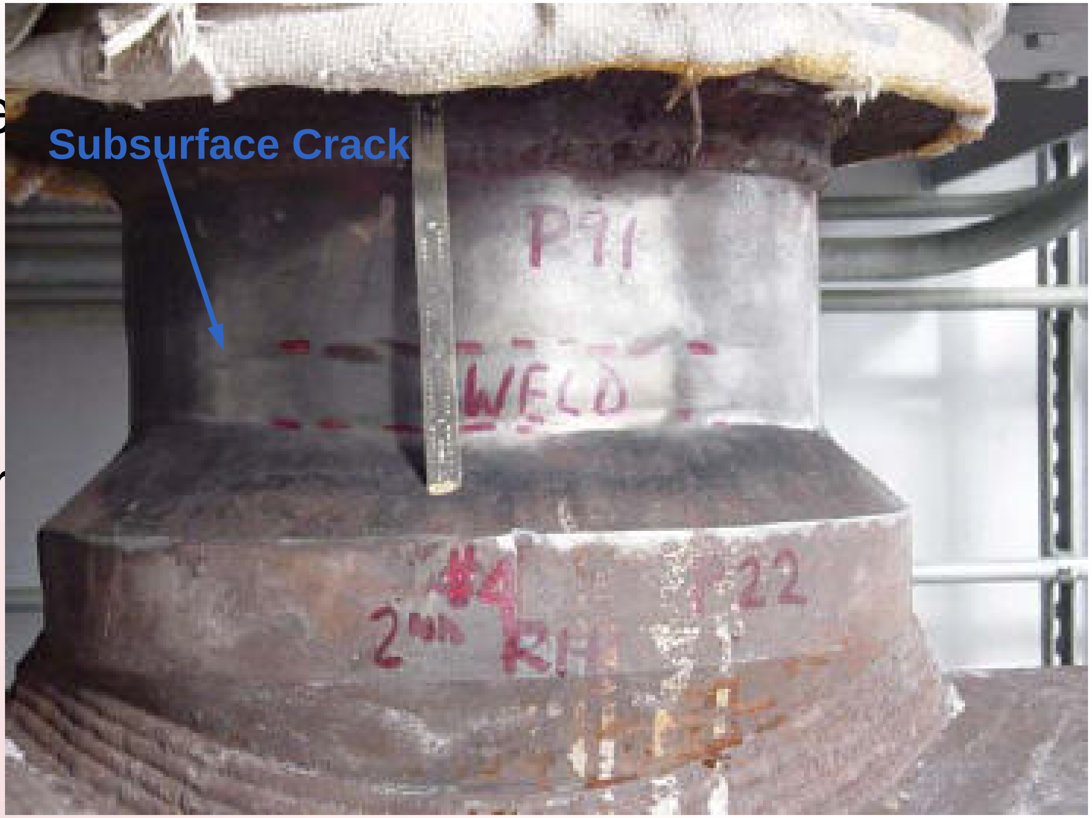


SHORT TERM DAMAGE

P91 to F22 Reheat Inlet Tee. Cracked on 91 side of weld from the inside

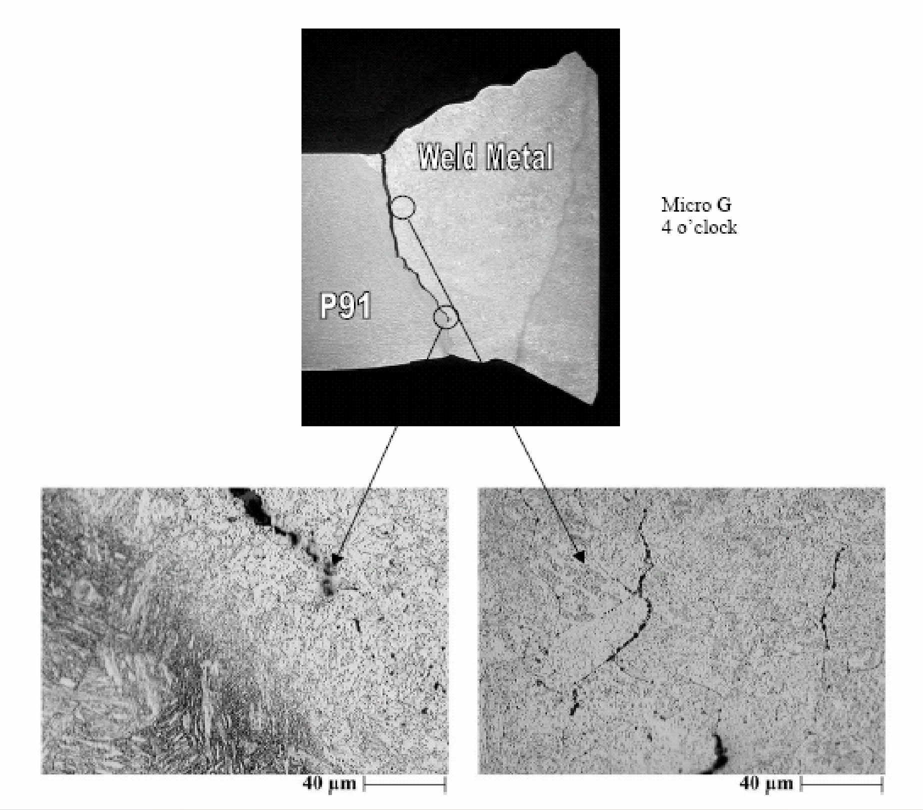
Attemperator spray causing a 400 ºF temperature difference from one side to another of this connection.

Design improvements BUT many components now in a state of uncertain damage



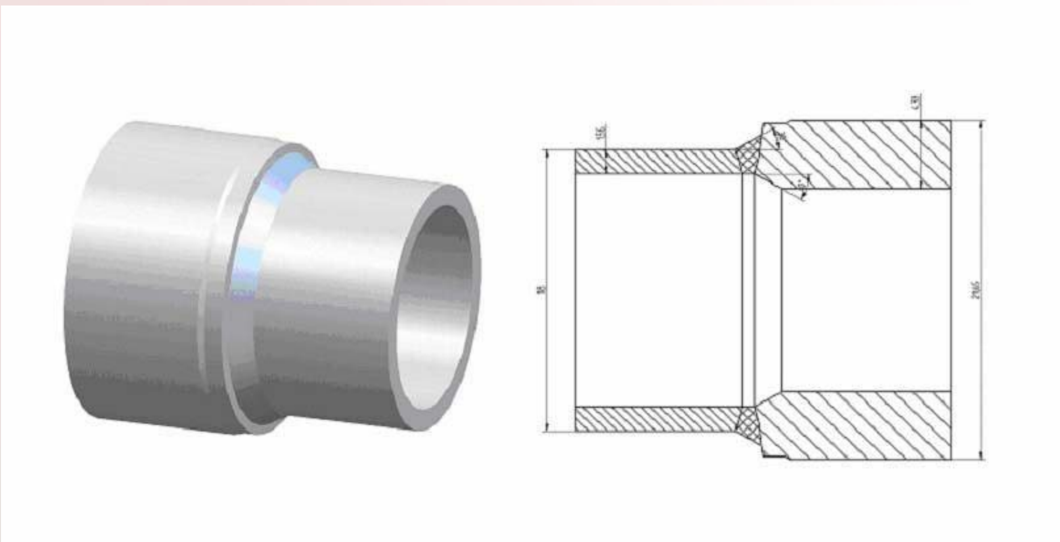
SHORT TERM DAMAGE

Leaking MS Pipe at Stop Valve,2 other Units with cracks. Attributed to insufficient transition between Grade 22 valve and Grade 91 piping, also issues of cold spring. redesigned transition piece was installed to reduce localized stresses.



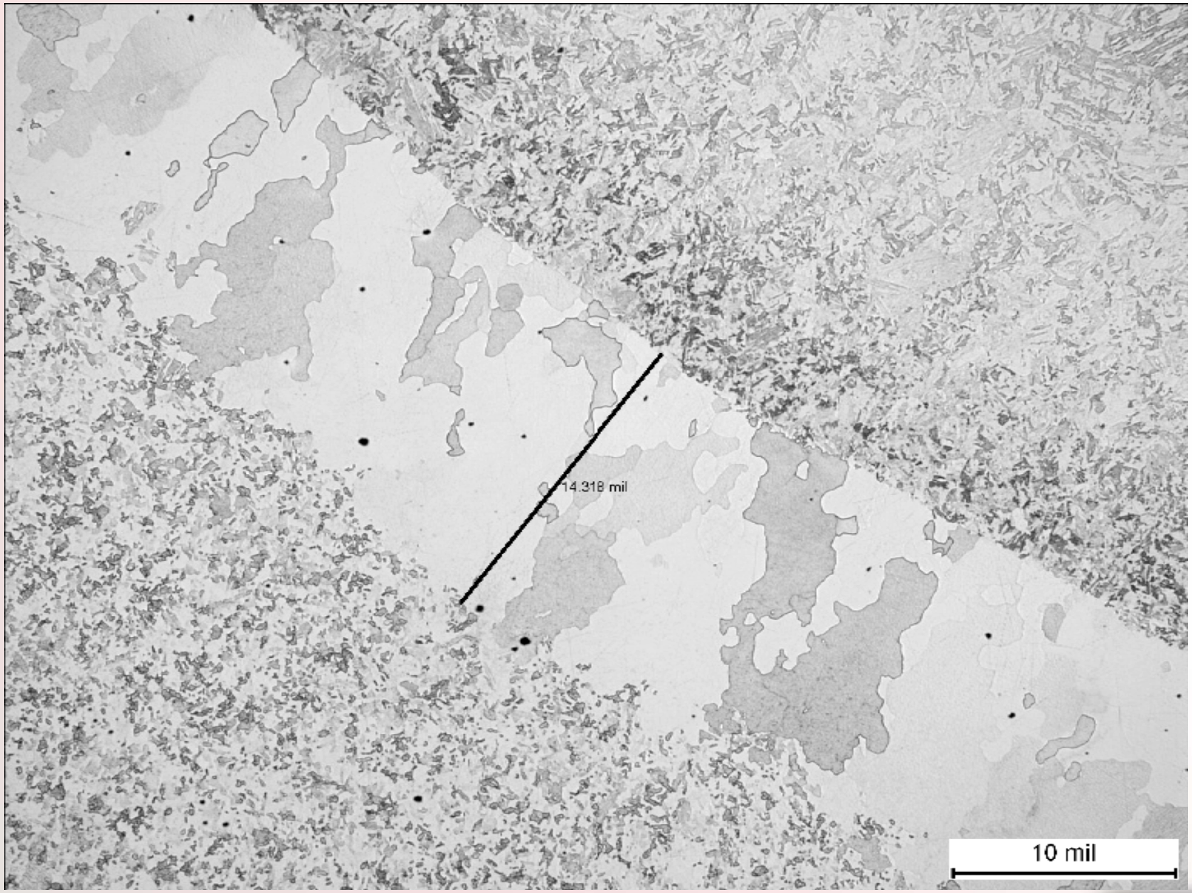
SHORT TERM DAMAGE

More generally, problems have been observed associated with Transitions, both with Geometric and Materials



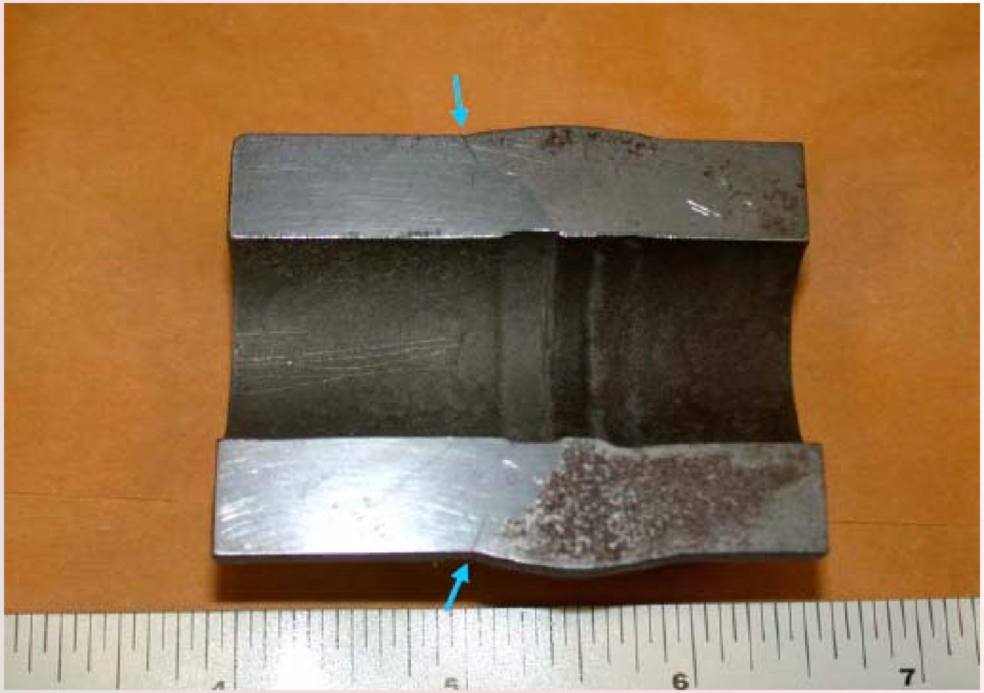
SHORT TERM DAMAGE

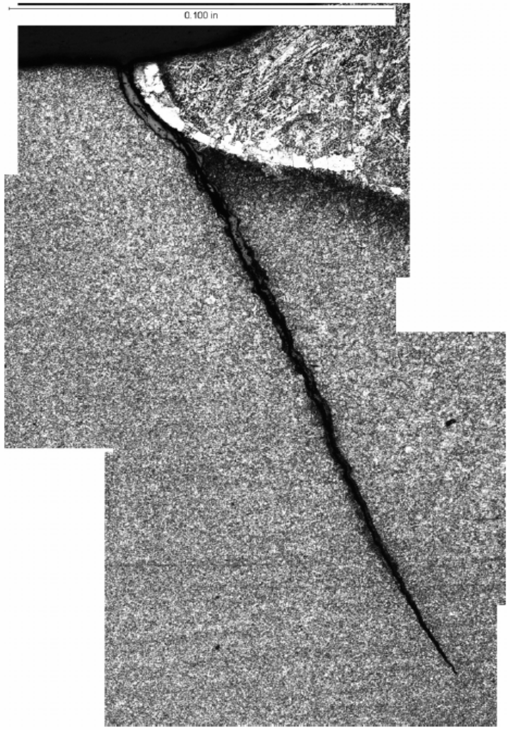
More generally, problems have been observed associated with Transitions, both with Geometric and Materials



Tubing

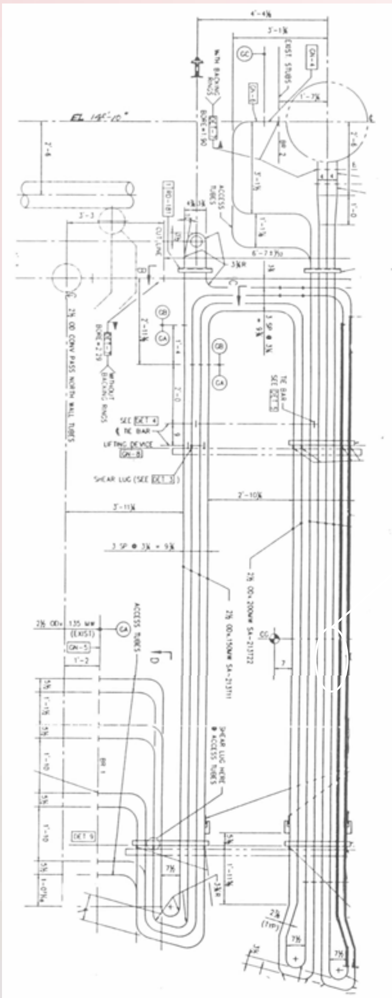
- **Failures appeared to initiate at the weld fusion line , propagation occurred away from the weld**

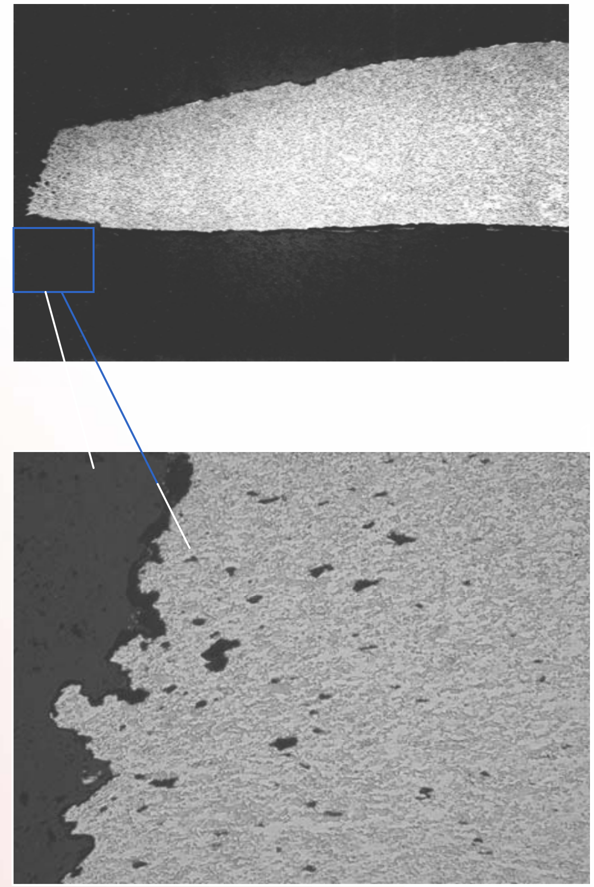




Magnification: 35X
Etchant: Vilellas Reagent

Tubing



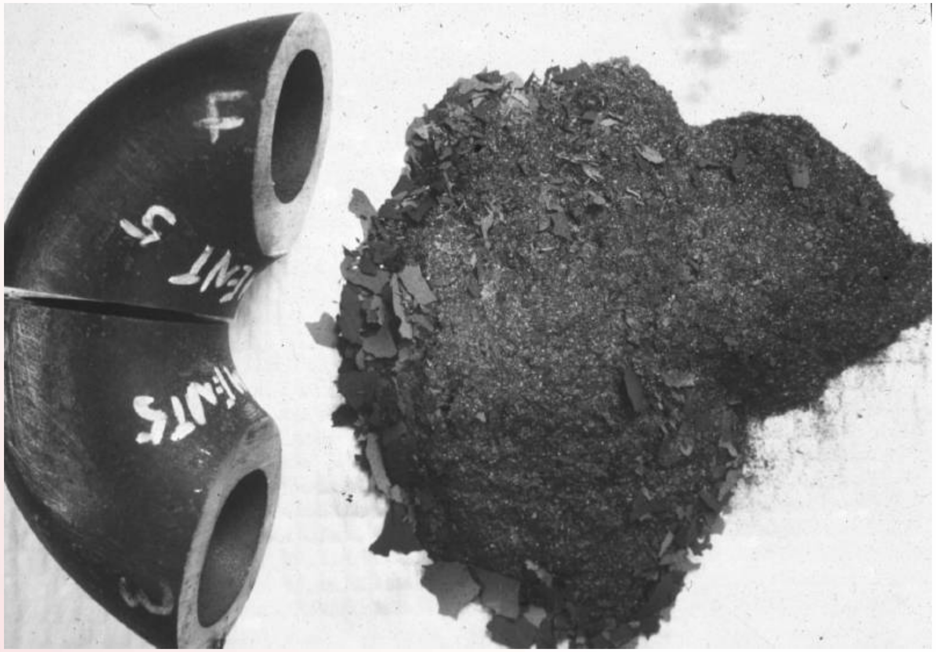


100x

T91 reheater outlet tube exhibits a relatively thin-lipped rupture.
The mounted rupture exhibits creep voids and clearly shows the extent of thinning

Tubing

- **Failures have also been linked to excessive steam side scale and exfoliation**



Tubing

Creep Strengthened Ferritic Steels exhibit complex behavior in Steam

Base metal

Dealloyed layer

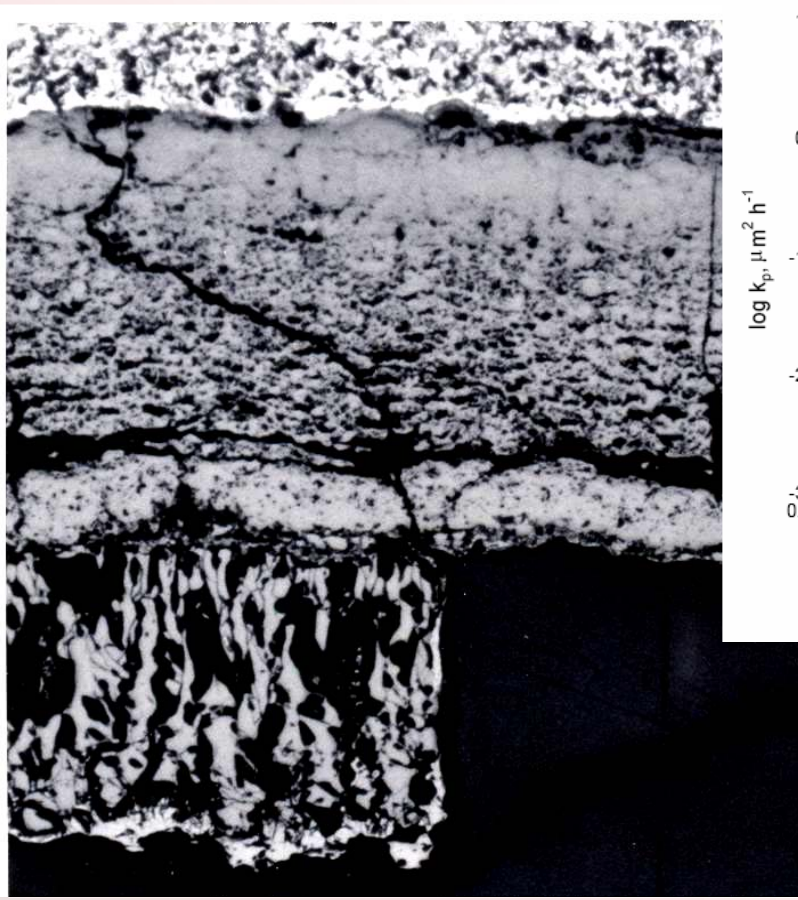
Spinel, $(Fe,Cr,Mo)_3O_4$

Laminated scale

Spinel, $(Fe,Cr,Mo)_3O_4$

Magnetite, Fe_3O_4

Hematite, Fe_2O_3



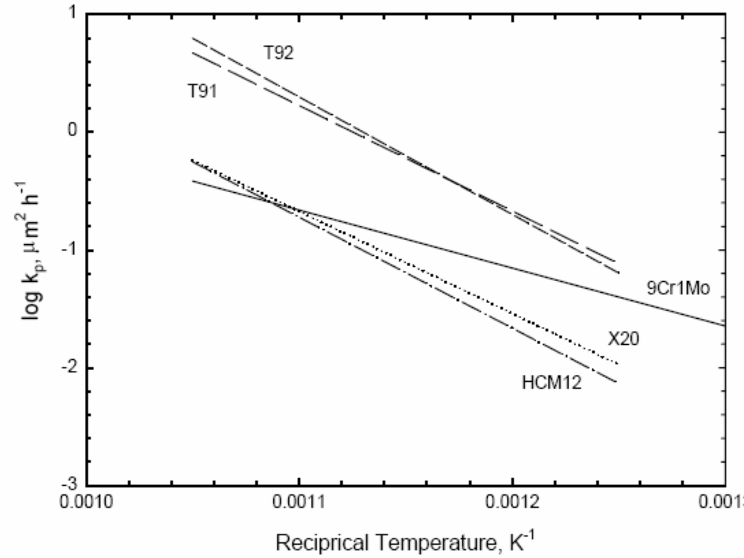
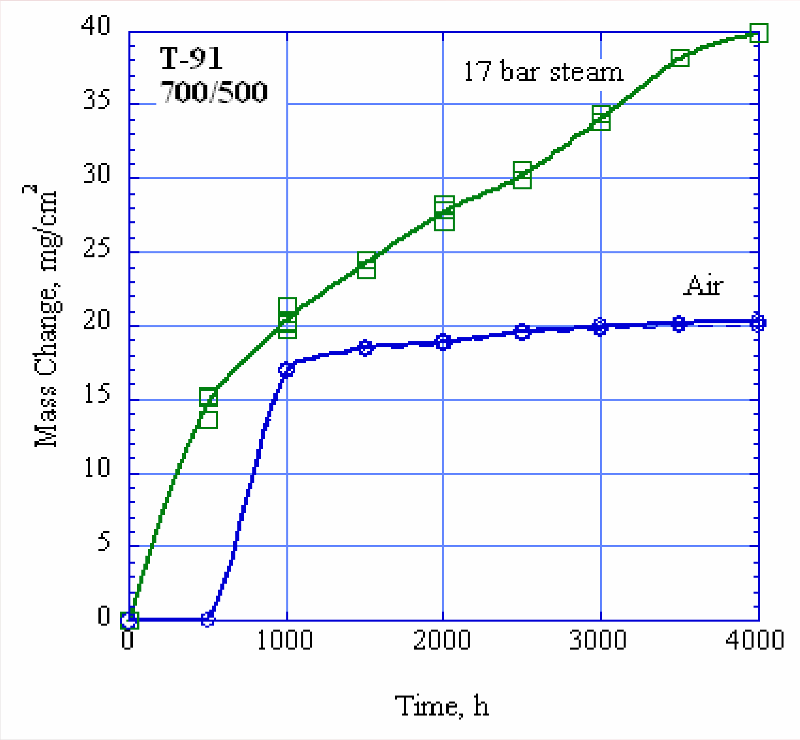
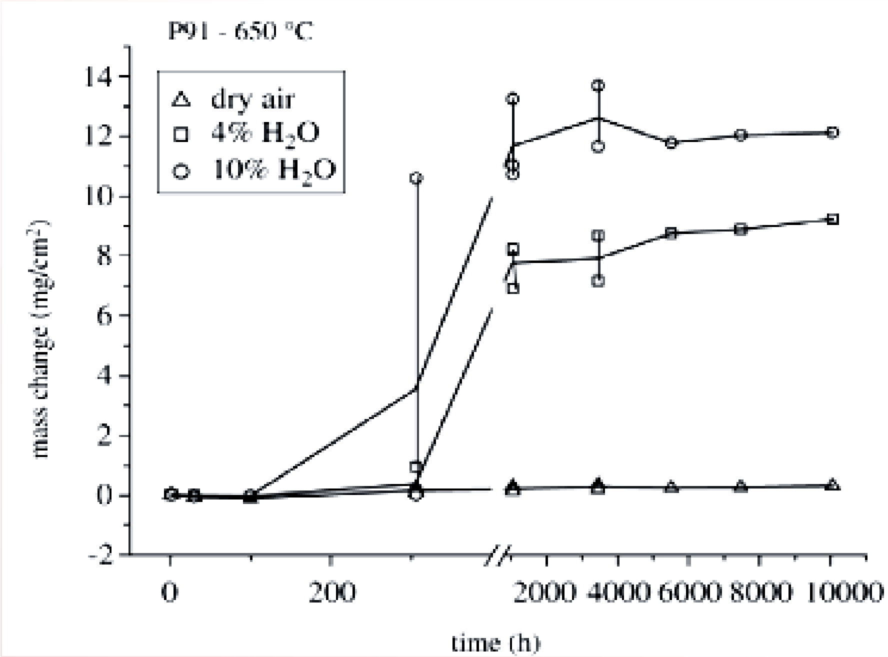


Figure 11 Parabolic rate constants for several steel alloys

Tubing

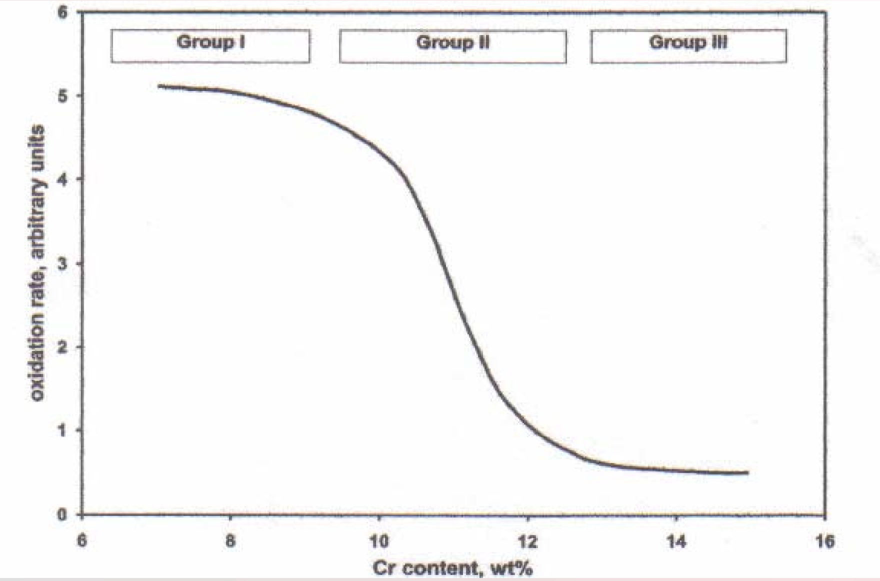
Significantly different behavior depending on exposure environment for example Grade 91 at 650ºC, 1202ºF?

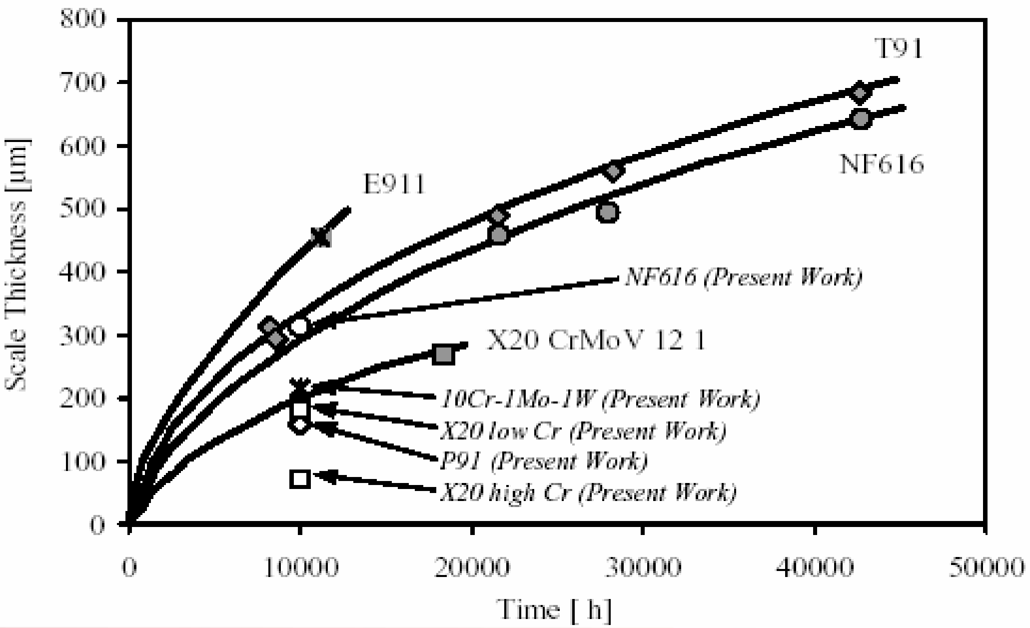




Tubing

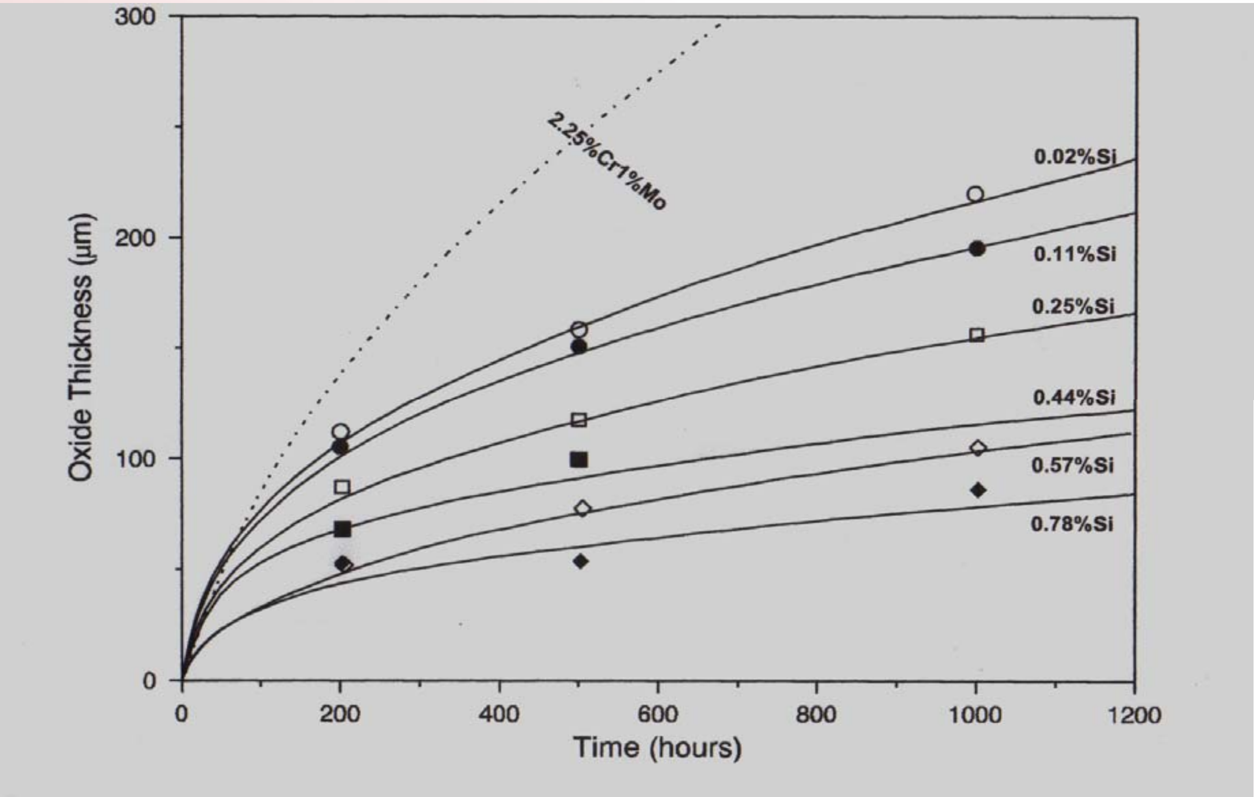
- **Significant improvement in oxidation resistance above about 12%Cr**
- **Useful operating metal temperature for Grade 91 – 600°C, 1112°F?**





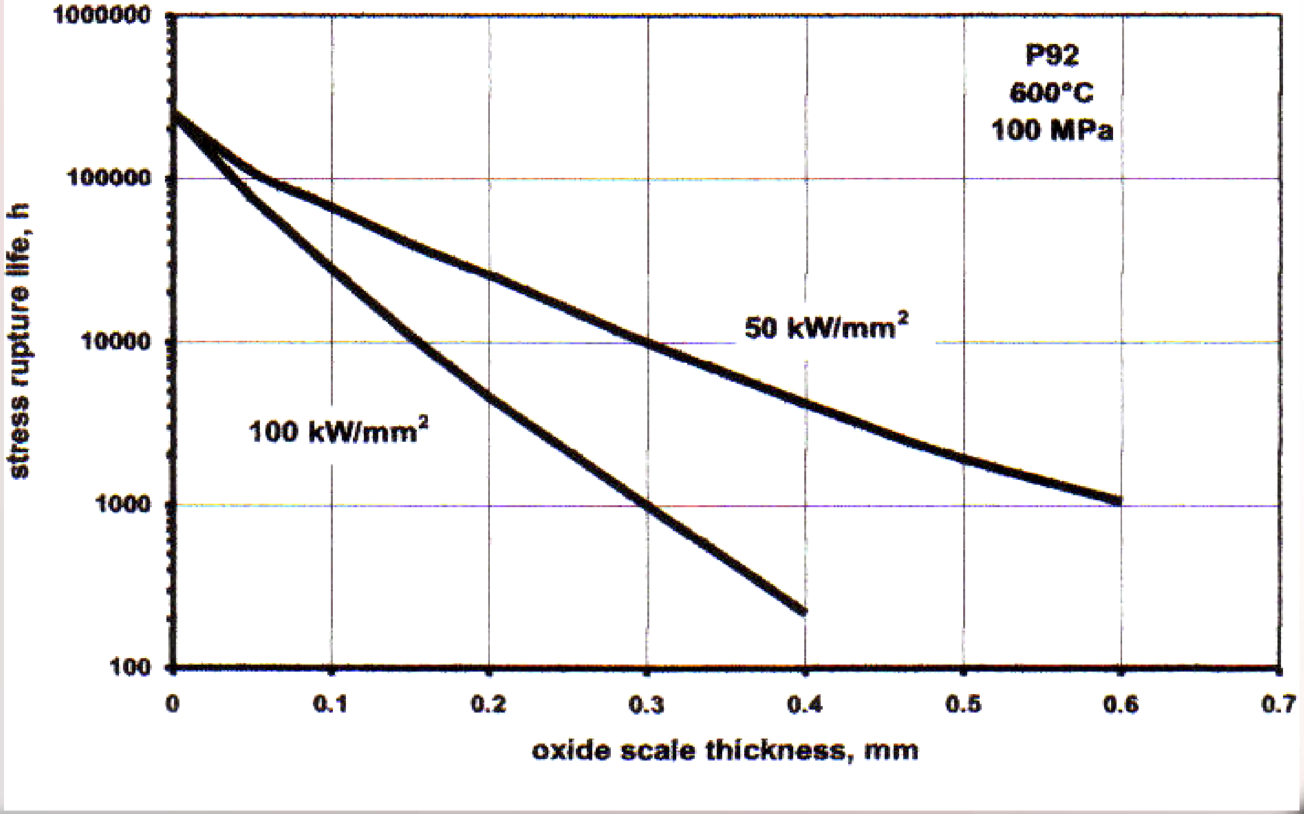
Tubing

Rate influenced by alloying elements such as Silicon
Variation of 2 times for Si levels within specification



Tubing

- **Exfoliation can cause**
  - **tube blockages-rapid overheating and failure**
  - **erosion in downstream components**
- **Thick scale will cause tube overheating & accelerated creep**

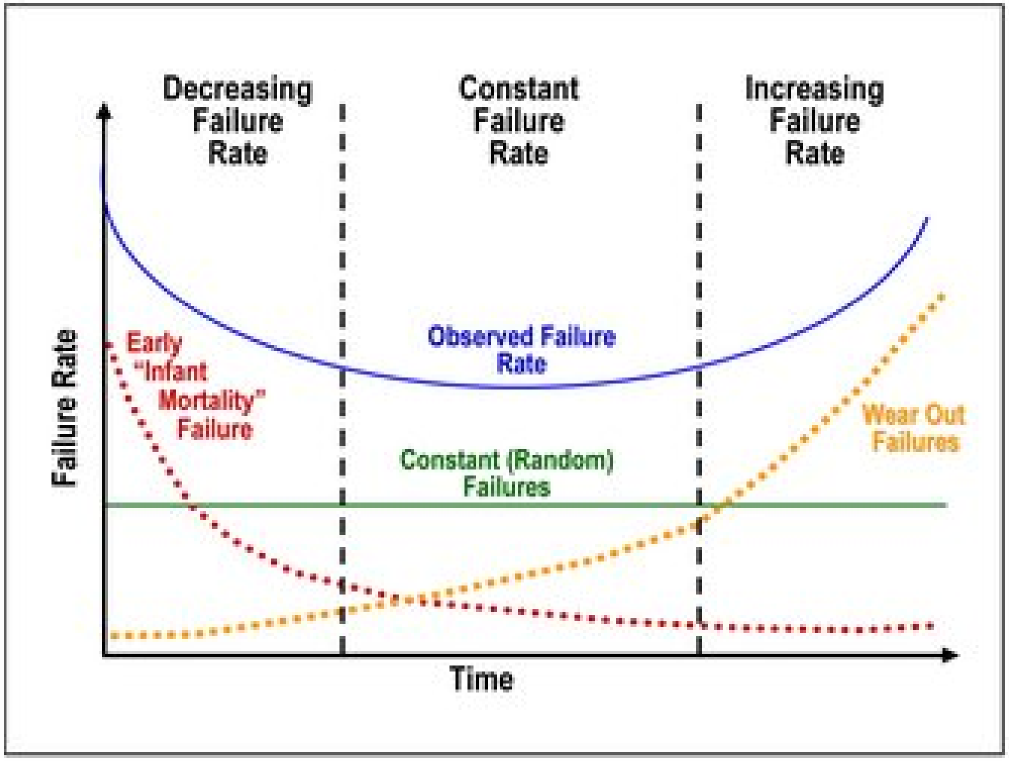


Eg Ennis 2002

LIFE MANAGEMENT

Traditionally summarized using a BATHTUB diagram

Good practice seeks to minimize stage 1 and 2 , then manage stage 3 (normally based on RISK).



LIFE MANAGEMENT

Management of Long Term End of life requires:

- Confidence (or definition of uncertainty) in initial design
- Confidence (or definition of uncertainty) in fabrication and the associated Quality Assurance – for the individual components, for all joints and the overall system
- Understanding of the factors affecting the development of long term damage so that tools for analysis, identification and quantification of damage are available
- Appreciation (and Quantification of) the consequences of failure, e.g safety, loss of generation, loss of money

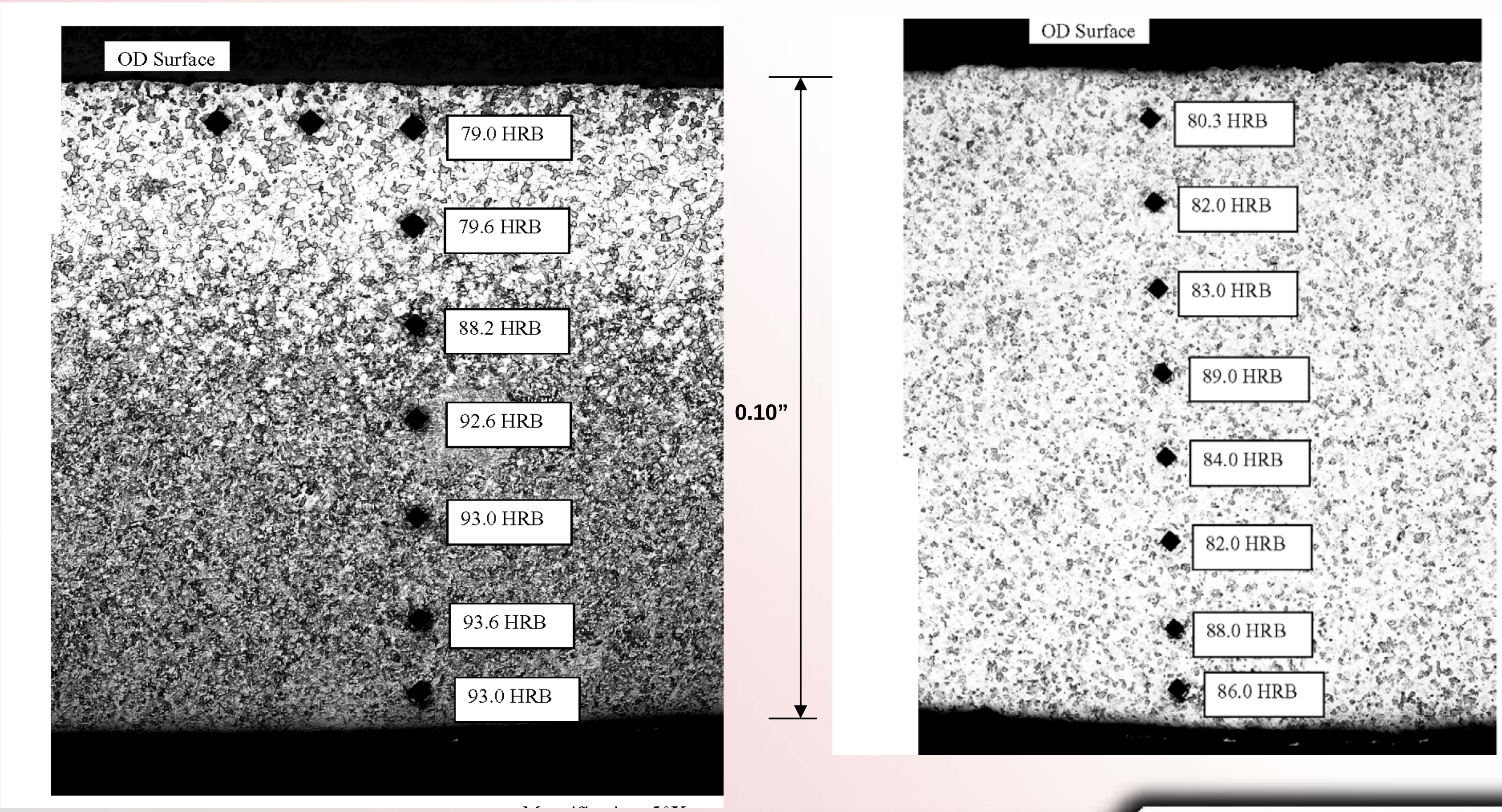
Starting point for many utilities with CSF Steels is an after installation review and inspection to provide some confidence in quality.

EXAMPLE PLANT ASSESSMENT

- Hardness tests on pipe bends of Grade 91 steel
  - Low readings found with Equotip tester
  - Retested with MIC 20 hardness tester
  - Low readings 149 – 190 BHN
- Replicas used to evaluate microstructure
  - Ferrite microstructure found in low hardness areas
- Concerns that OD surface tests may not be representative of bulk
- Material samples taken to determine through-wall extent and measure composition, creep properties etc
- Followed up with fleet wide testing and increase in QA acceptance testing for new components

EXAMPLE - Main Steam Pipe Sample

Microstructural Variations Found

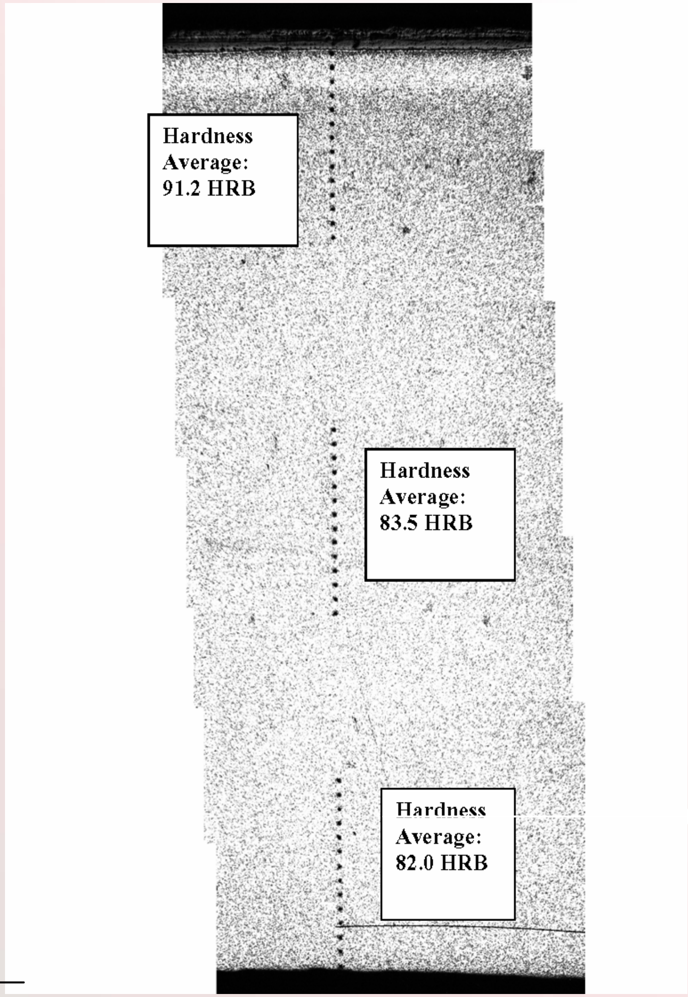


EXAMPLE – Plug Sample

OD

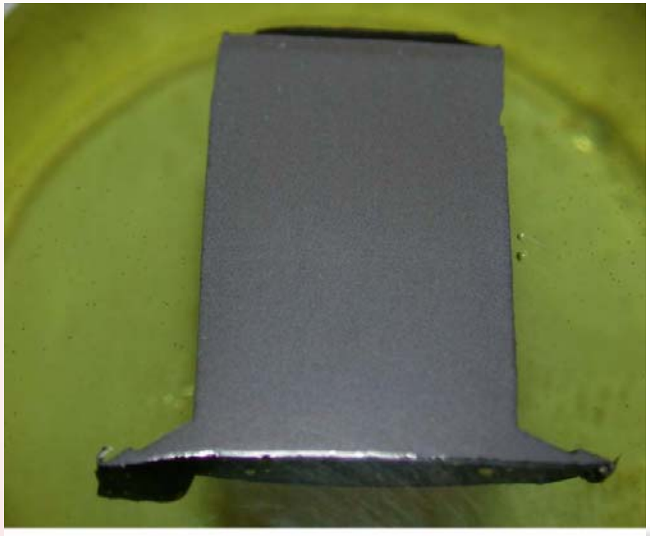
0.75"

ID



Lowest hardness at ID

Plug Cross-Section



LIFE MANAGEMENT SOLUTIONS

Established need to reduce uncertainty in as installed components by

- **GREATER CONTROL OF COMPOSITION, for example**
  - Take account of influence of Ni + Mn in HT schedule
  - For creep assess factors such as Al:N ratio
  - For oxidation resistance check minimum level of chromium
- **GREATER CONTROL DURING FABRICATION, for example**
  - Temperature including heating rate, hold peak & cooling rate
  - No uncontrolled thermal excursions
  - Prevent moisture contact before tempering / PWHT
  - Increased quality assurance review and inspection

Because of concerns with long term performance of parent and welds there is also the need for increased instrumentation and in-service inspection

CONCLUDING REMARKS

The advantages offered by creep strengthened ferritic steels can only be realized with careful control of fabrication methods. Since ASME codes provide general information further engineering judgement is frequently of benefit.

An Integrated Life Management Strategy for CSF steels should include review and quality assurance during the procurement and fabrication stages. However, even with good acceptance and validation checks effort will be needed during service to evaluate component performance.

THANK YOU

BACK

WITH BEST COMPLIMENTS:

WYMAN GORDON PIPE & FITTINGS A PCC COMPANY

(USA, UK & CHINA)

JIANGSU CHENGDE STEEL TUBE SHARE CO. LTD., CHINA

*** SEAMLESS PIPES & TUBES FOR BOILERS ***

*** SEAMLESS PIPES AND FITTINGS FOR POWER PLANT PIPING ***

***OD 38.1 MM – 1200 MM ***

CARBON, ALLOY, STAINLESS, NICKEL AND SUPER ALLOYS

Authorized suppliers:

VENUS INTERNATIONAL FZE
P.O. Box – 103976
Dubai – U.A.E.

Email:info@venusfze.com