STRUCTURING AND ENGINEERING OF INDIAN DATA BASE ON MECHANICAL AND CORROSION METALLURGY

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Indira Gandhi Centre for Atomic Research

Kalpakkam (India)

India has long experience in maintaining Scientific Data Bases

*Materials Science and Engineering

- Through professional bodies
  - Indian Institute of Metals
  - Materials Research Society of India
- Through Individual/ Research Institutes

MATERIALS SCIENCE AND ENGINEERING

Compilation of important scientific information in India was initiated as early as in 1977 ***(Indian Institute of Metals)***

periodically updated

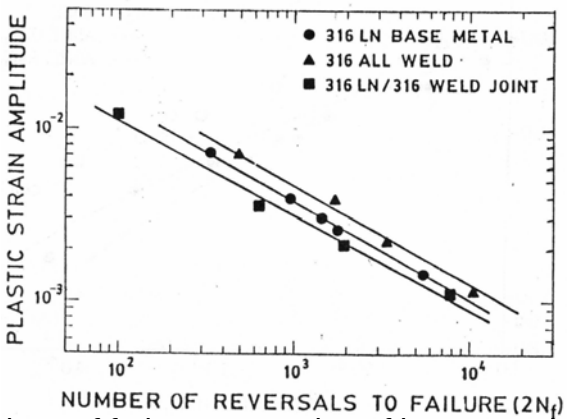
about the scientists
specialization
equipment capability
research and development programme

Scientific Data on Alloy Phase Diagrams (IIM)

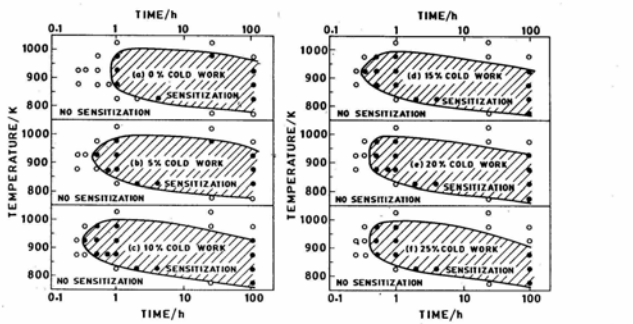
Data on Non-ferrous Metals (MRSI/TIFAC)

IGCAR

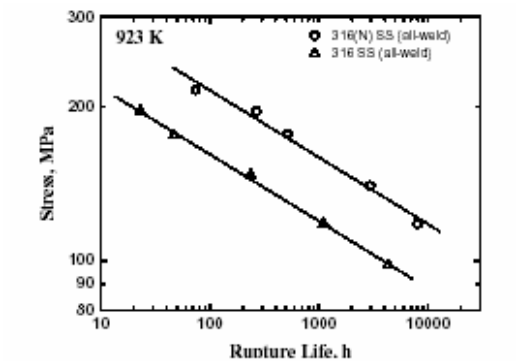
- **Data have been generated over three decades.**
- **Valuable and extensive data on mechanical and corrosion properties of various materials**



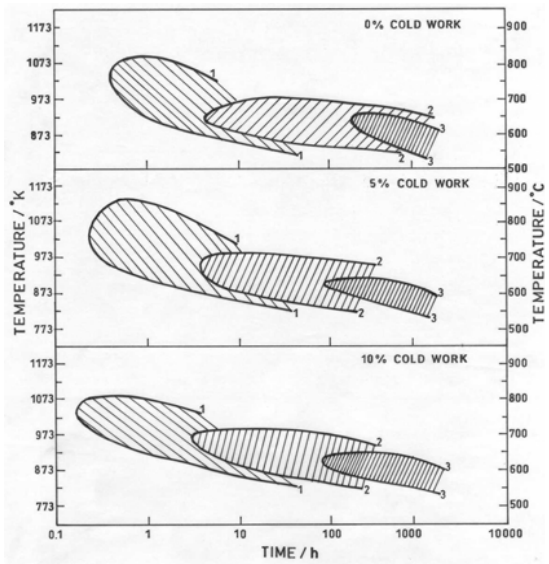
Comparison of fatigue properties of base metal and weld metal of type 316 stainless steel



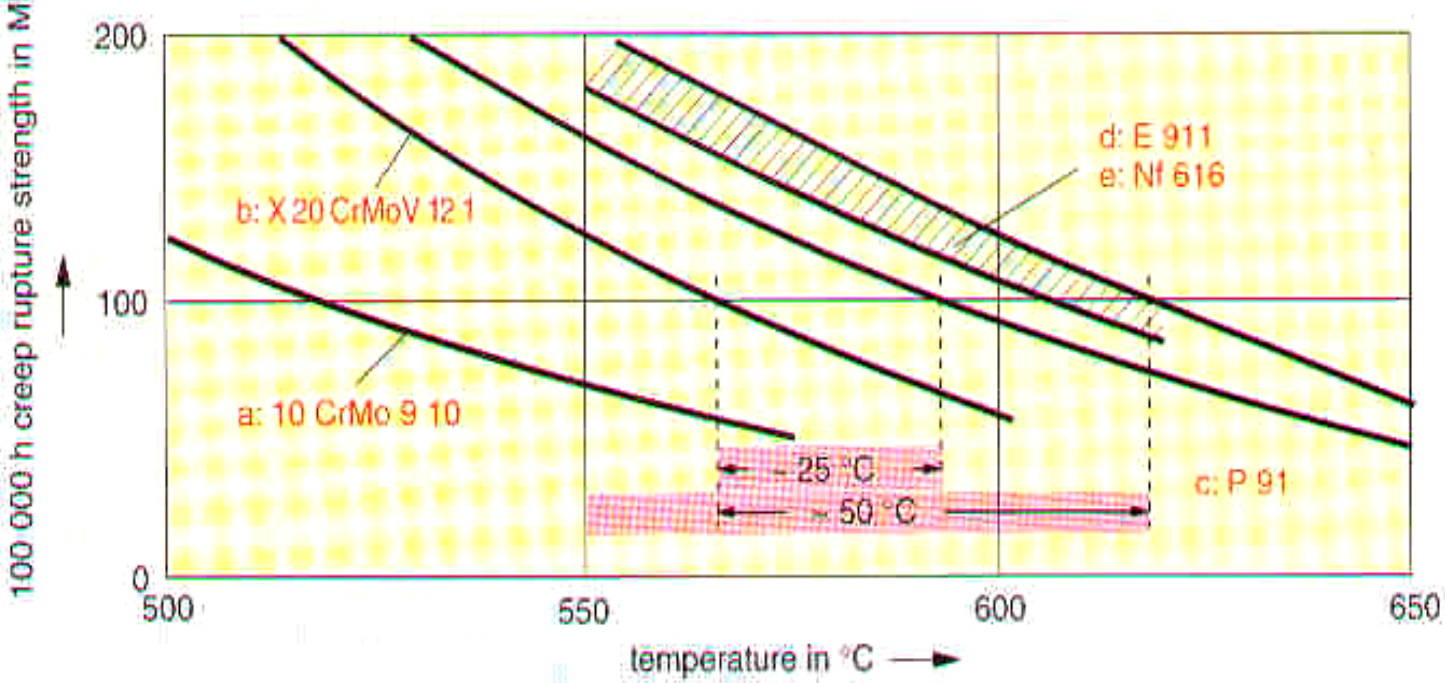
TTS diagrams for 304 SS with different degrees of cold work. ○ – no attack; ◒ – light attack; ● – attack in boiling $Cu–CuSO_4–H_2SO_4$ medium.



Comparison of creep rupture strengths of 316 and 316(N) SS weld metals



Steel	C	Cr	Mo	W	V	Nb	N	B	wt.-%
a)	0.1	2.5	1.0	–	–	–	–	–	
b)	0.2	12.0	1.0	–	0.30	–	–	–	
c)	0.1	9.0	1.0	–	0.20	0.05	0.05	–	
d)	0.1	9.0	1.0	1.0	0.20	0.05	0.07	–	
e)	0.1	9.0	0.45	1.8	0.20	0.06	0.05	0.002	



1,00,000 h Creep Rupture Strength of Boiler Steels

MATERIALS

Austenitic SS
304
316
316 LN
ALLOY D9
PE16

METALURGICAL VARIABLES

Grain Size (316)
Heat To Heat Variation (316)
Thermal Ageing (316)
Weld Joint(316 & 316LN)
Weld Metal (316 & 316LN)
Cold Wok (304, 316)
Ti/C Ratio (D9)

Ferritic Steels
2.25Cr-1Mo
9Cr-1Mo
MODIFIED 9Cr-1Mo

METALURGICAL VARIABLES

Weld Joint
Weld Metal (2.25Cr-1Mo)
Austenitisation Temperature
PWHT (2.25Cr-1Mo)

Dissimilar Weld Joint
(Inconel 182 Electrode)
2.25Cr-1Mo / Alloy 800
9Cr-1Mo / Alloy 800
Modified 9Cr-1Mo / Alloy 800

Large source of Data on Creep, Fatigue, Tensile, Fracture and corrosion properties on more than 25 materials

National Team on

Mechanical and Corrosion Metallurgy

Dr. Baldev Raj, IGCAR — **Chairman**
Dr. R. K. Dayal, IGCAR — **Convenor**

Members:

Dr. I. Chattoraj, NML, Jamshedpur
Dr. A. O. Surendranathan, NITK, Surathkal
Dr. Kulvir Singh, Corp R&D, BHEL , Hyderabad
Dr. Subodh Kumar, IISc, Bangalore
Dr. K. Laha, IGCAR
Shri R.V. Subba Rao, IGCAR

Aim:

Data quality
generation of basic data based on recognized/ standard test methods

Data accessibility
information of data and source of data/ laboratories/ equipment/ specialisation

Data archiving
preservation of old data; MS/PhD thesis work in PDF format

Plant experience; failure analysis

DATA SHEETS

- Elevated Temperature Tensile Properties
- Creep And Creep Rupture Properties
- Fatigue Properties
- Fracture Resistance From Transition Temperature And Fracture Mechanics Approach
- Corrosion Properties

Material History

- Melting, Processing And Heat Treatment
- Chemical Composition
- Grain Size
- Hardness
- Inclusion Content

Creep data

Data Sheet Format

Test temperature (K)	Stress (MPa)	Time to reach total strain (h) 0.5 %	1.0 %	2.0 %	5.0 %	Time to tertiary creep (h)	Minimum creep rate	Time to rupture (h)	Elongation (%)	Reduction in area (%)

Graphical presentation of Creep data

- Microstructural change with creep exposure
- Failure location in weld joint

Low Cycle Corrosion Fatigue Data

Data Sheet Format

Temperature (K)	É (S^{-1})	ε_{ta} (S^{-1})	ε_{pa} (S^{-1})	N_{20} (No of cycles)	σ_a MPa

- **É : strain rate (s^{-1})**
- **t_h : strain hold time on tension / compression side (h)**
- **ε_{ta} : total strain amplitude control between the gauge length**
- **ε_{pa} : plastic strain amplitude at half life**
- **N_{20} : number of cycles corresponding to a 20 % decrease in the peak tensile load as compared with the value at Nf /2**
- **σ_a : stress amplitude (MPa) at N_{20} /2**
- **σ_{max}: maximum stress (MPa) at N_{20} / 2**
- **σ_r : stress (MPa) at the end of the hold period at N_{20} / 2.**

Low Cycle Corrosion Fatigue Data with hold time data (Creep-Fatigue interaction)

Temperature (K)	É (S^{-1})	ε_{ta} (S^{-1})	Hold time (min)	ε_{pa} (S^{-1})	N_{20} No of Cycles)	σ_a (MPa)	σ_{max} (MPa)	σ_r (MPa)

Sample DATA SHEETS

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SENSITIZATION DATA FOR TYPE 316 STAINLESS STEEL

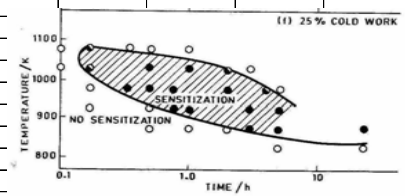
Chemical composition of material (wt%)

Cr	Ni	Mo	Mn	Si	S	P	C	N	B
16.46	12.43	2.28	1.69	0.64	0.006	0.025	0.054	0.053	NA

Material History: mill annealed and 25 % cold worked

Test Standard : ASTM A-262 practice E

Temp in °C	Temp in °K	Time to sensitization in h
810	1083	0.20
800	1073	0.18
790	1063	0.17
780	1053	0.17
770	1043	0.17
760	1033	0.17
750	1023	0.17
740	1013	0.18
730	1003	0.19
720	993	0.20
710	983	0.22
700	973	0.26
690	963	0.30
680	953	0.38
670	943	0.45
660	933	0.58
650	923	0.70
640	913	0.90
630	903	1.20
620	893	1.70
610	883	2.20
600	873	2.60
590	863	4.00
580	853	6.00
570	843	11.00
560	833	20.00
550	823	30.00



CCR = 790 °K/h

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SENSITIZATION DATA FOR TYPE 316L(N) STAINLESS STEEL

Chemical composition of material (wt%)

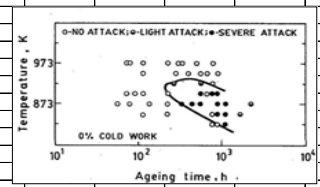
Cr	Ni	Mo	Mn	Si	S	P	C	N	B	V	Co	Cu
17.18	10.23	1.85	1.54	0.585	0.005	0.022	0.043	0.075	NA	0.061	0.23	0.207

Material History: mill annealed and 0 % cold worked

Test Standard : ASTM A-262 practice E

Temp in °K	Time to sensitization in h
700	15.50
690	9.00
680	7.00
670	6.00
660	5.00
650	4.40
640	5.00
630	5.80
620	7.00
610	10.00
600	16.00
590	25.00
580	40.00
570	60.00
560	200.00
550	640.00

CCR = 0.43 °K/h



Sample DATA SHEETS

Indira Gandhi Centre for Atomic Research, Kalpakkam, India

SENSITIZATION DATA FOR TYPE 316 STAINLESS STEEL

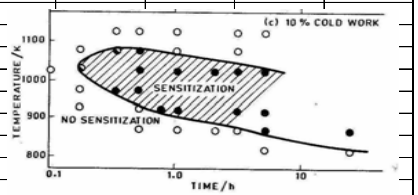
Chemical composition of material (wt%)

Cr	Ni	Mo	Mn	Si	S	P	C	N	B
16.46	12.43	2.28	1.69	0.64	0.006	0.025	0.054	0.053	NA

Material History: mill annealed and 10 % cold worked

Test Standard : ASTM A-262 practice E

Temp in °C	Temp in °K	Time to sensitization in h
810	1083	0.25
800	1073	0.22
790	1063	0.19
780	1053	0.19
770	1043	0.18
760	1033	0.17
750	1023	0.16
740	1013	0.17
730	1003	0.18
720	993	0.20
710	983	0.23
700	973	0.27
690	963	0.30
680	953	0.38
670	943	0.46
660	933	0.58
650	923	0.70
640	913	0.90
630	903	1.30
620	893	1.90
610	883	2.80
600	873	4.00
590	863	4.80
580	853	9.00
570	843	14.00
560	833	22.00
550	823	42.00



CCR = 765 °K/h

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SENSITIZATION DATA FOR TYPE 316L(N) STAINLESS STEEL

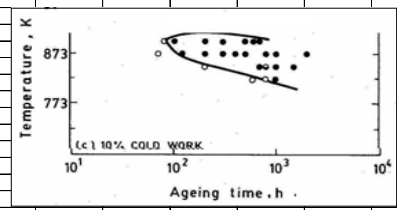
Chemical composition of material (wt%)

Cr	Ni	Mo	Mn	Si	S	P	C	N	B	V	Co	Cu
17.18	10.23	1.85	1.54	0.585	0.005	0.022	0.043	0.075	NA	0.061	0.23	0.207

Material History: mill annealed and 10 % cold worked

Test Standard : ASTM A-262 practice E

Temp in °K	Time to sensitization in h
710	7.00
700	3.00
690	3.00
680	3.00
670	3.30
660	3.80
650	4.00
640	4.80
630	6.00
620	8.00
610	12.00
600	18.00
590	27.00
580	40.00
570	64.00
560	120.00
550	200.00



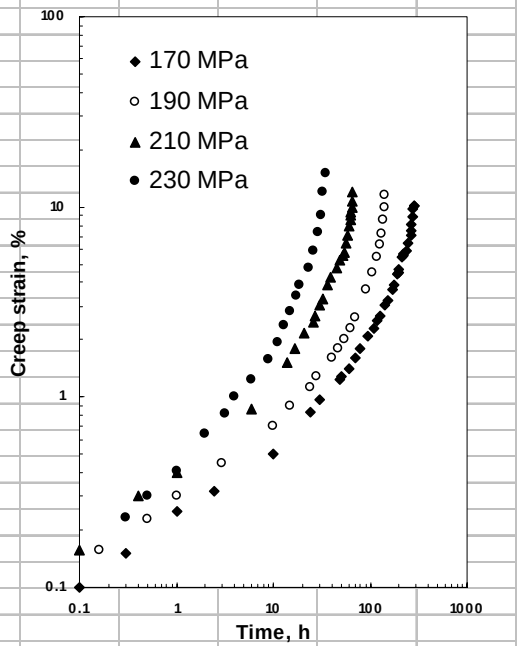
CCR = 0.73 °K/h

Sample Data Sheets

Creep data on 1Cr1Mo0.25V rotor forging steel in normalised and tempered condition

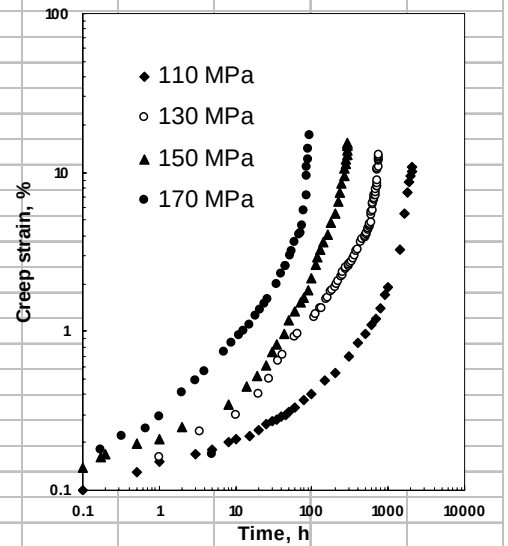
RC575-170MPa

Time	Strain
0	0.0123
0.1	0.1
0.3	0.15
1	0.25
2.5	0.32
10	0.5
24	0.83
30	0.965
48	1.248
50	1.283
60	1.4
70	1.6
80	1.8
96	2.088
110	2.3
120	2.536
127	2.686
144	3.047
152	3.245
168	3.65
176	3.89
192	4.412
195	4.537
198	4.734
216	5.479
218	5.59
224	5.7
240	5.912
251	6.5
264	7.038
266	7.5
268	8.099
271	8.8
272	9.717
288	10.078
289	10.2



RC600-110MPa

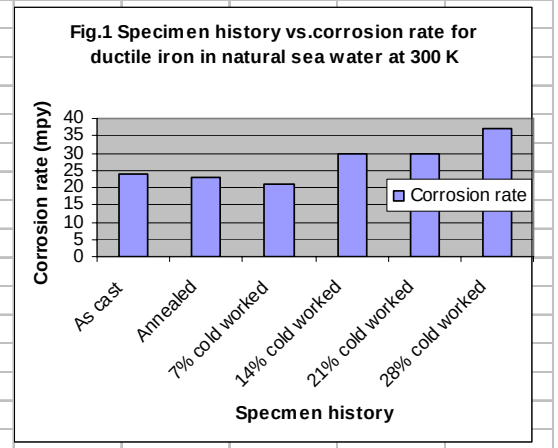
Time	Strain
0	0
0.1	0.1
0.5	0.13
1	0.15
3	0.17
5	0.18
8	0.2
10	0.21
15	0.22
20	0.24
25	0.26
30	0.27
35	0.28
40	0.29
45	0.3
50	0.31
60	0.33
80	0.37
100	0.4
150	0.49
200	0.55
300	0.7
400	0.84
500	0.97
600	1.1
700	1.2
800	1.4
900	1.7
1000	1.9
1400	3.3
1600	5.5
1800	7.5
1900	8.8
2000	9.5
2050	10.1
2073	10.8



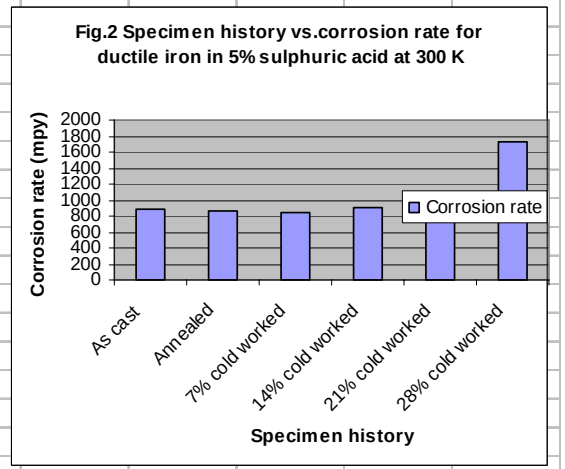
Sample Data Sheets

Data on the aqueous corrosion of Ductile Iron in the alloyed and unalloyed conditions

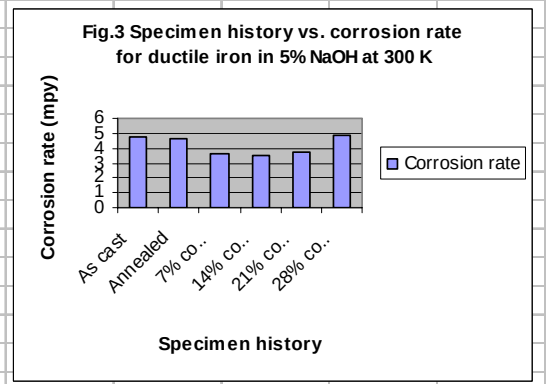
Specimen	Corrosion rate
As cast	24
Annealed	23
7% cold w	21
14% cold v	30
21% cold v	30
28% cold v	37



Specimen	Corrosion rate
As cast	874
Annealed	869
7% cold w	844
14% cold v	901
21% cold v	984
28% cold v	1718



Specimen	Corrosion rate
As cast	4.8
Annealed	4.6
7% cold w	3.6
14% cold v	3.5
21% cold v	3.7
28% cold v	4.9



Sample Data Sheets

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Creep Properties of 2.25Cr-1Mo Base Metal, Weld Metal and Weld joint at 773 K

Chemical composition base metal (wt%)

Cr	Mo	Si	Mn	C
2.18	0.93	0.18	0.47	0.06
P	S	Fe		
0.008	0.008	Bal.		

Material History: 12 mm plate
Normalized at 1223 K for 17 minutes
Tempered at 1003 K for 60 minutes

Chemical composition deposited weld metal (wt%)

Cr	Mo	Si	Mn	C
2.3	1.1	0.4	0.72	0.05
P	S	Fe		
0.02	0.012	Bal.		

Test Standard: E 139 - 00

Creep Properties of 2.25Cr-1Mo Base Metal at 773 K

Material History: Post Weld Heat Treatment (PWHT) at 973 K for 60 minutes

Stress, Mpa	Creep Rate / s	Rupture Life, h	Elongation,%	Reduction,%
190	6.45E-10	13803	17	77
200	9.10E-10	7243	18	81
220	2.96E-09	1674	20	85
230	6.92E-09	1045	21	86
250	1.59E-08	243	24	87
275	5.45E-08	80	26	87

Sample Data Sheets

Creep Properties of 2.25Cr-1Mo Weld Metal at 773

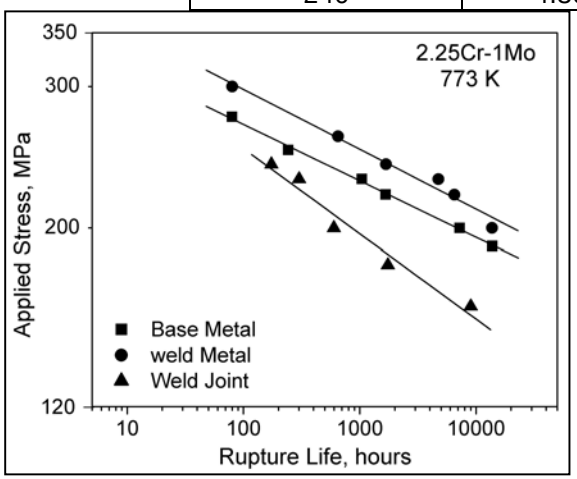
Material History: Post Weld Heat Treatment (PWHT) at 973 K for 60 minutes

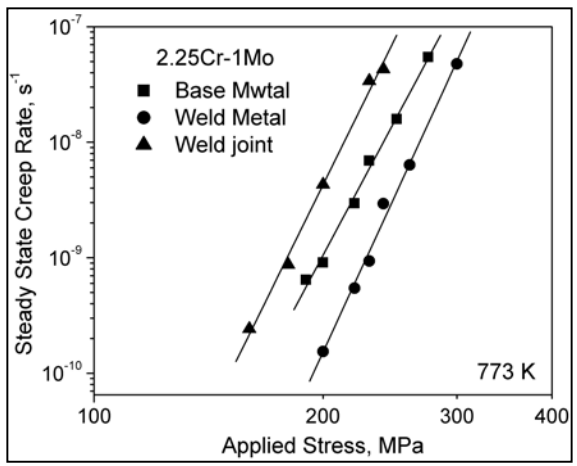
Stress, Mpa	Creep Rate / s	Rupture Life, h	Elongation,%	Reduction,%
200	1.54E-10	13725	9	53
220	5.46E-10	6501	9	60
230	9.38E-10	4743	10	62
240	2.94E-09	1680	12	69
260	6.35E-09	652	15	72
300	4.78E-08	80	19	79

Creep Properties of 2.25Cr-1Mo Weld Joint at 773 K

Material History: Post Weld Heat Treatment (PWHT) at 973 K for 60 minutes

Stress, MPa	Creep Rate / s	Rupture Life, h	Elongation, %	Reduction, %
160	2.42E-10	9005	9	62
180	8.70E-10	1744	11	75
200	4.30E-09	599	13	81
230	3.40E-08	301	14	84
240	4.30E-08	174	15	86





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Creep Properties of 9Cr-1Mo Base Metal and Weld joint at 823 K

Chemical composition base metal (wt%)

Cr	Mo	Si	Mn	C
8.36	0.93	0.49	0.46	0.1
P	S	Fe		
0.008	0.002	Bal.		

Material History: 12 mm thick plate
Normalized at 1223 K for 15 minutes
Tempered at 1053 K for 120 minutes

Chemical composition deposited weld metal (wt%)

Cr	Mo	Si	Mn	C
8.9	0.98	0.52	0.52	0.12
P	S	Fe		
0.003	0.03	Bal.		

Test Standard: ASTM E 139 - 00

Creep Properties of 9Cr-1Mo Base Metal at 823 K

Material History: Post Weld Heat Treatment (PWHT) at 998 K for 60 minutes

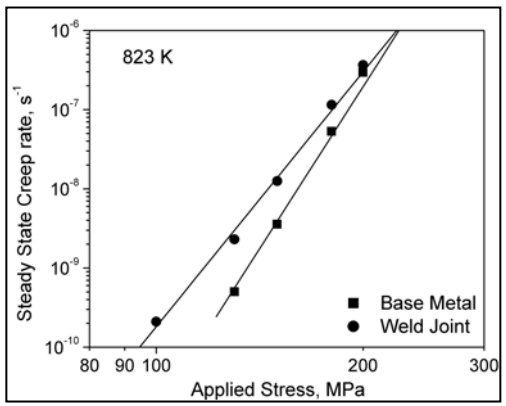
Stress, Mpa	Creep Rate / s	Rupture Life, h	Elongation,%	Reduction,%
130	5.00E-10	12980	17	77
150	3.56E-09	3914	18	81
180	5.30E-08	563	20	85
200	2.95E-07	93	21	86
240	1.66E-06	11.5	24	87

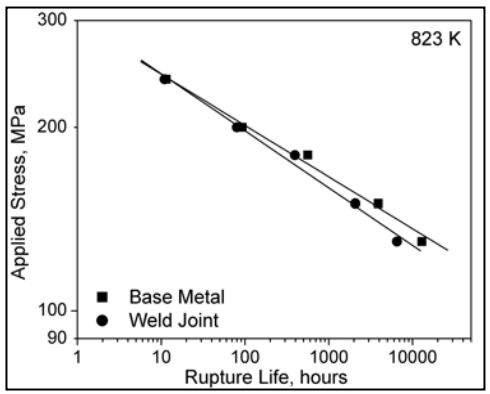
Sample Data Sheets

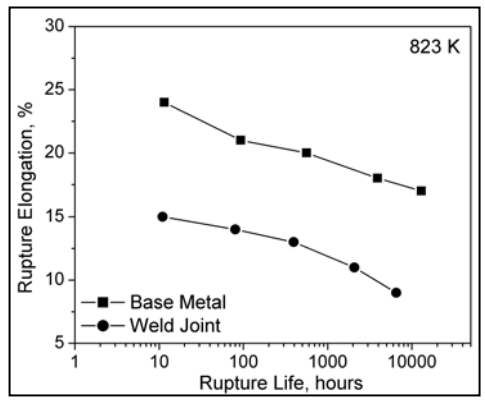
Creep Properties of 9Cr-1Mo Weld Joint at 823 K

Material History: Post Weld Heat Treatment (PWHT) at 998 K for 60 minutes

Stress, MPa	Creep Rate / s	Rupture Life, h	Elongation, %	Reduction, %
100	2.10E-10			
130	2.30E-09	6523	9	62
150	1.25E-08	2070	11	75
180	1.15E-07	394	13	81
200	3.65E-07	80	14	84
240	1.83E-06	11	15	86







Sample Data Sheets

Indira Gandhi Centre for Atomic Research

Tensile Properties of 9Cr-1Mo Steel and simulated HAZ of its weld joint

Chemical composotion of material (wt %)

Cr	Mo	Si	Mn	P	S	C
8.36	0.93	0.49	0.46	0.008	0.002	0.1
Fe						
Balance						

Test Standard: ASTM E8M - 04

Tensile Properties of 9Cr-1Mo Steel Base Metal

Material History: Normalized at 1223 K for 15 minutes
tempered at 1053 k for 120 minutes

Temperature, K	Yield Stress, Mpa	UTS,Mpa	Elongation,%	Reduction,%
298	522	681	20.8	74.5
473	459	590	17.1	76.5
523	435	586	15.7	76.7
548	448	580	15.8	76.7
573	449	574	16.7	73.2
598	449	567	14.8	75.7
623	451	569	14.4	73.7
673	440	548	14.8	73.5
723	423	506	15.6	73.9
773	389	441	16.1	82.3
823	354	376	16.4	87.5
873	280	292	18.8	93.7

Sample Data Sheets

Tensile Properties of Simulated Intercritical HAZ in 9Cr-1Mo Weld Joint

Material History: Soaking at 1138 K for 5 minutes, oil quenchingair cool
Tempered at 973 K for 60 minutes, air cool

Temperature, K	Yield Stress, Mpa	UTS,Mpa	Elongation,%	Reduction,%
298	502	650	21.2	74.5
473	434	558	17.5	75.8
523	433	549	15.4	76.5
548	434	557	16.3	76.4
573	431	547	15.2	75.7
598	431	553	15.9	72.4
623	428	540	15.9	73.2
673	402	523	15.9	74.2
723	393	480	16.1	78.2
773	374	413	16.3	82.2
823	328	347	16.9	89.1
873	263	276	17.8	92.6

Tensile Properties of Simulated Fine Grain HAZ in 9Cr-1Mo Weld Joint

Material History: Soaking at 1200 K for 5 minutes, oil quenchingair cool
Tempered at 973 K for 60 minutes, air cool

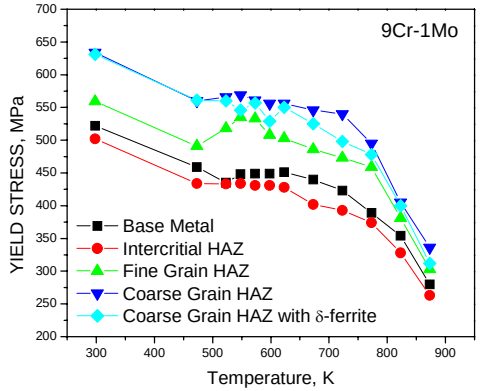
Temperature, K	Yield Stress, Mpa	UTS,Mpa	Elongation,%	Reduction,%
298	559	700	17.4	74.3
473	491	616	15.5	78.6
523	518	624	14.1	76.5
548	535	635	13.8	77.6
573	533	645	12.7	77.9
598	508	613	13.5	77.9
623	503	612	13.2	74.5
673	486	575	13.7	74.5
723	473	538	14.4	74.5
773	459	500	15.9	81
823	381	421	18.9	86.2
873	303	319	22.4	98.1

Sample Data Sheets

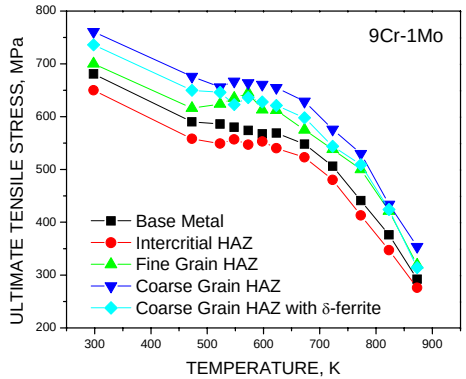
Tensile Properties of Simulated Coarse Grain HAZ in

Material History: Soaking at 1323 K for 5 minutes, oil quenchingair cool
Tempered at 973 K for 60 minutes, air cool

Temperature, K	Yield Stress, Mpa	UTS, Mpa	Elongation, %	Reduction, %
298	634	761	15.3	73.3
473	560	676	12.6	77.5
523	566	656	12.6	77.4
548	569	667	11.7	74.8
573	561	664	11.7	76
598	556	661	11.9	75.5
623	556	655	12.2	74.5
673	546	629	12.8	75.5
723	540	576	12.9	77.7
773	495	530	14	83.3
823	405	434	15	88.4
873	336	354	16	90.9

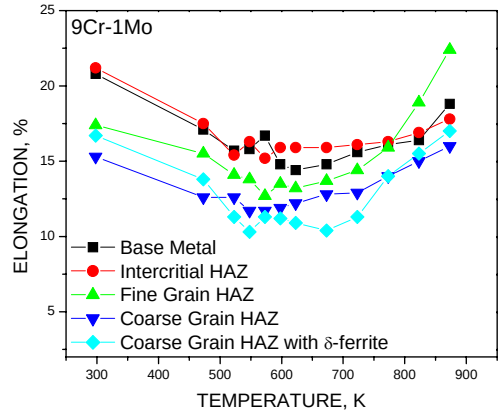


Tensile Properties of Simulated Coarse Grain with Delta Ferrite in 9Cr-1Mo Wel



Material History: Soaking at 1483 K for 5 minutes, oil quenchingair cool
Tempered at 973 K for 60 minutes, air cool

Temperature, K	Yield Stress, Mpa	UTS, Mpa	Elongation, %	Reduction, %
298	631	736	16.7	73.5
473	561	650	13.8	75
523	560	646	11.3	73
548	546	623	10.3	74
573	557	636	11.3	69.2
598	529	628	11.2	66.1
623	550	621	10.9	69.2
673	525	598	10.4	67.8
723	498	544	11.3	69.5
773	478	509	14	75
823	400	424	15.5	86.9
873	312	314	17	92.1



Sample Data Sheets

Indira Gandhi Centre for Atomic Research, Kalpakkam, India

Tensile Properties of 2.25Cr-1Mo base metal and simulated HAZ of its weld joint

Chemical composition of the steel (wt %)

Cr	Mo	Si	Mn	C
2.18	0.93	0.18	0.47	0.06
P	S	F		
0.008	0.008	Bal.		

Test Standard: ASTM E8M - 04

Tensile Properties of 2.25Cr-1Mo base metal

Material History: Normalised at 1223 K for 17 minutes, air cool
Tempered at 1003 K for 60 minutes, air cool

Temperature, K	Yield stress, M Pa	UTS, M Pa	Elongation,%	Reduction,%
298	476	591	19.3	81.2
423	424	522	16	80.8
473	421	523	14.9	81.9
523	430	549	15.2	78.2
548	439	545	14.3	78.5
573	444	548	14.3	76.4
623	443	542	14.9	78.5
673	428	524	14.4	79.1
723	405	486	13.8	83.4
773	391	465	13.2	83.2
823	373	410	14.3	88.8
873	338	340	15.5	92.4

Sample Data Sheets

Tensile Properties of Simulated Intercritical HAZ in 2.25Cr-1Mo Weld Joint

Material History: Soaking at 1100 K for 5 monutes, oil wuenching
Tempering at 973 K for 60 minutes, air cooling

Temperature, K	Yield Stress, Mpa	UTS,Mpa	Elongation,%	Reduction,%
298	339	480	25	83
423	330	428	22.7	81.2
473	318	429	21.1	80.8
523	315	443	19.3	78.6
573	312	467	17.6	77.4
623	308	475	16.5	75.5
673	296	470	17.2	77.2
723	288	443	17.1	79.3
773	287	400	16.4	81.9
823	273	350	16.8	82.9
873	237	285	18.5	88.7

Tensile Properties of Simulated Fine Grain HAZ in 2.25Cr-1Mo Weld Joint

Material History: Soaking at 1173 K for 5 monutes, oil wuenching
Tempering at 973 K for 60 minutes, air cooling

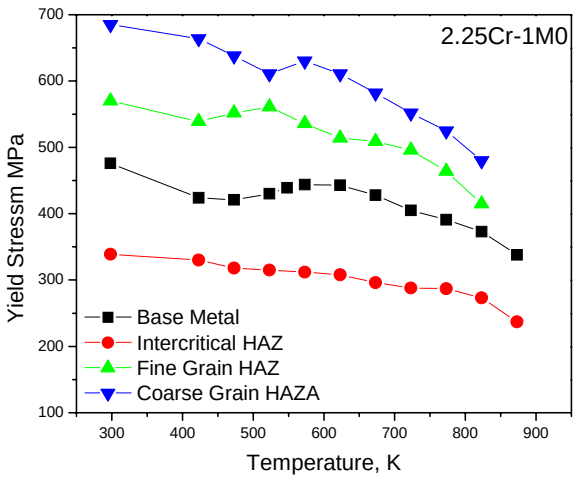
Temperature, K	Yield Stress, Mpa	UTS, Mpa	Elongation, %	Reduction, %
298	570	674	17.8	81.5
423	539	607	14	80.8
473	552	624	13.9	81.1
523	561	624	14	80
573	536	616	12.6	79
623	514	585	14.8	75.9
673	509	545	15.7	78.1
723	496	507	16.3	79.5
773	464	441	15.8	81.2
823	415	350	15.8	87.5

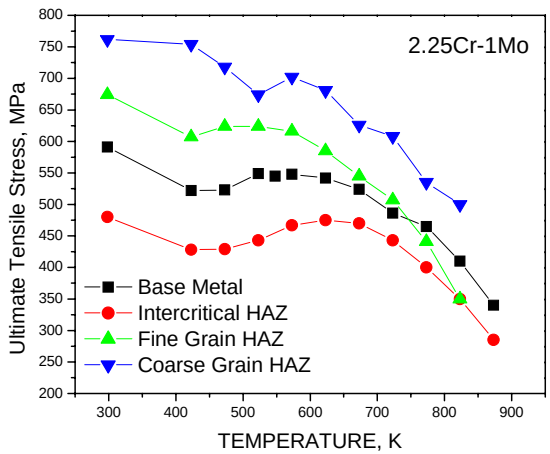
Sample Data Sheets

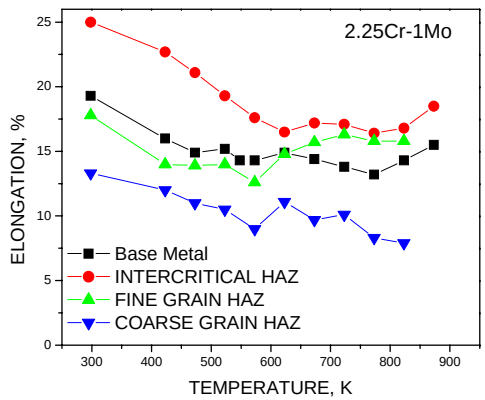
Tensile Properties of Simulated Coarse Grain HAZ in 2.25Cr-1Mo Weld Joint

Material History: Soaking at 1473 K for 5 monutes, oil wuenching
Tempering at 973 K for 60 minutes, air cooling

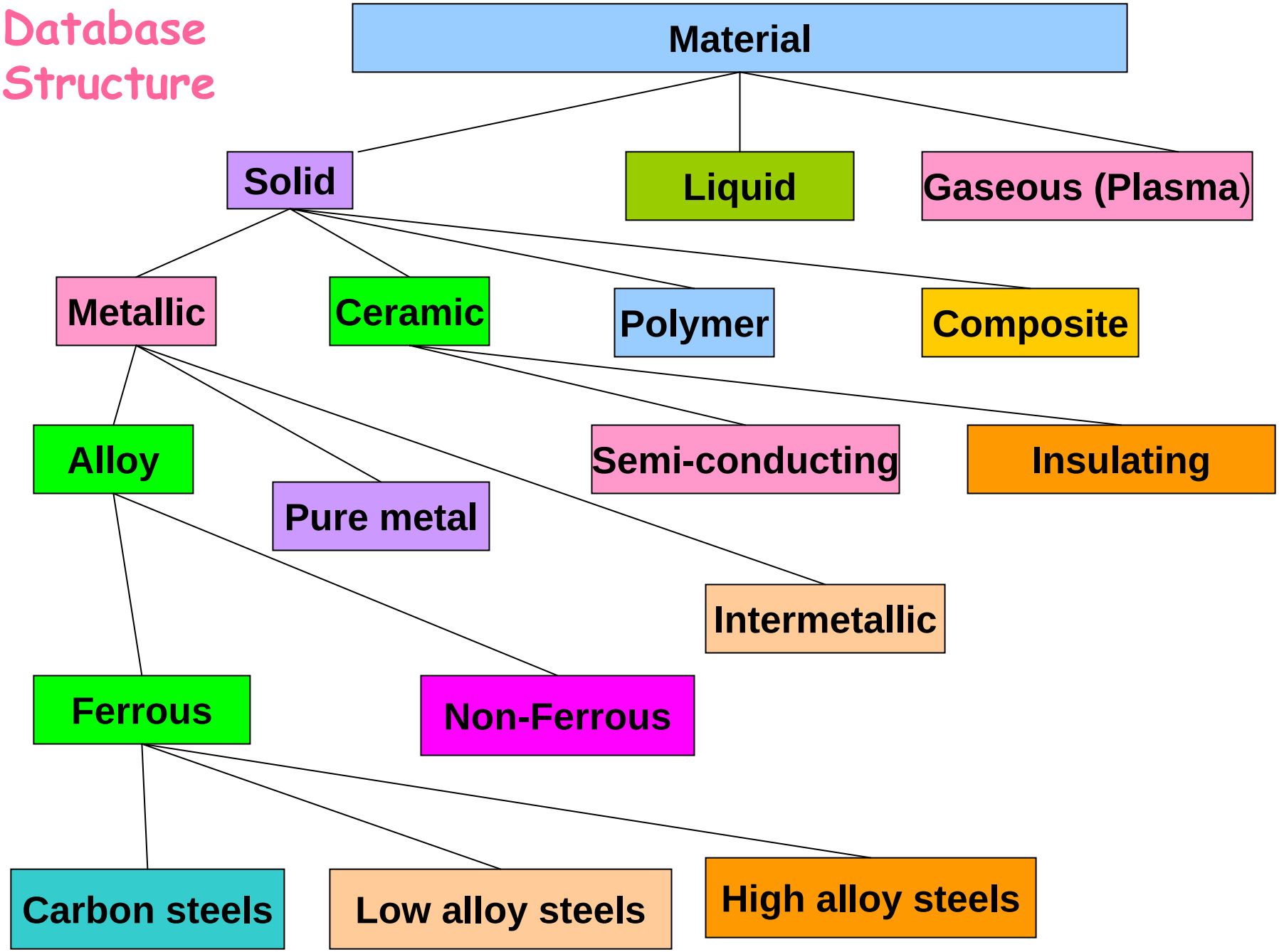
Temperature, K	Yield Stress, Mpa	UTS, Mpa	Elongation, %	Reduction, %
298	685	762	13.3	65.3
423	664	754	12	60.3
473	638	718	11	59.7
523	611	674	10.5	61.2
573	630	702	9	56.7
623	611	681	11.1	63.2
673	582	626	9.7	65.6
723	552	608	10.1	59.1
773	525	535	8.3	57.7
823	480	500	7.9	50







Database Structure



CONCLUSIONS

- **Enormous amount of data on Mechanical and Corrosion properties of Materials have been generated in Research Laboratories in India**

- **A working group has been formed with members from different laboratories with periodic review**

- **Work has been initiated to collect these Data in form of Data sheets**

- **One Independent web site will be open soon for public access of the data**

- **Financial and manpower support expected from Dept of Science and Technology, (Govt. of India) for above work.**


THANKS