

Design of a new generation of 12% chromium steels

KME - 710

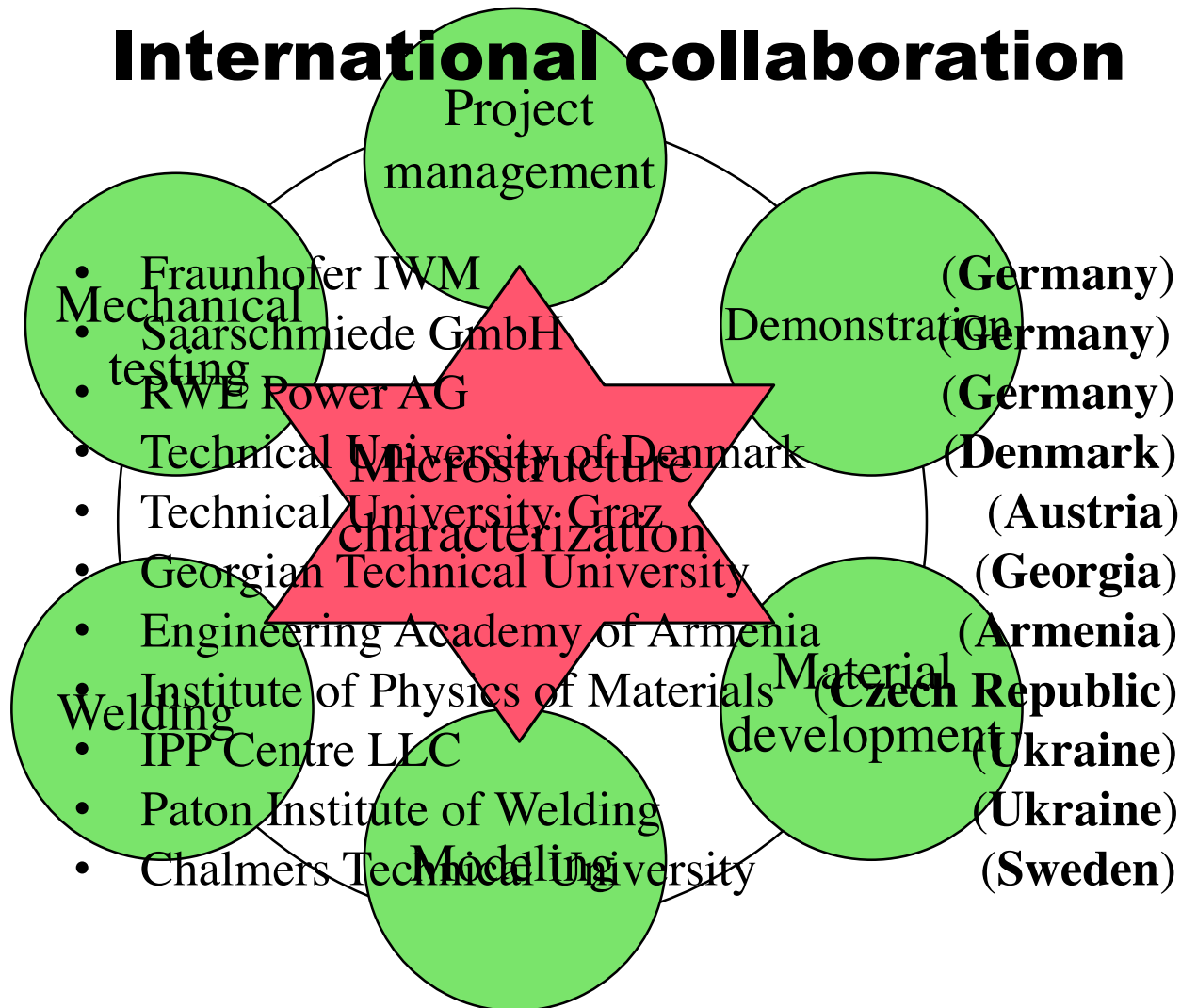
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Robert Lawitzki, and Hans-Olof Andrén

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Cooperation partners

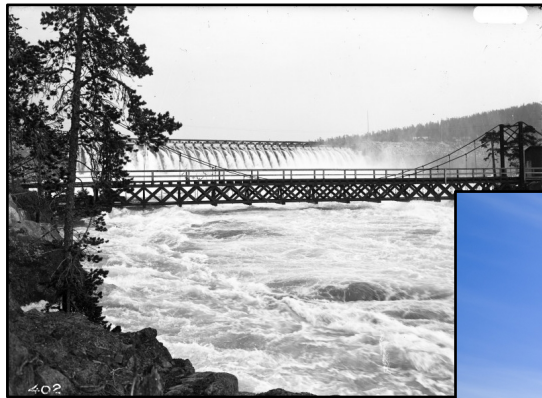
<i>Project participants:</i>	Lennart Johansson	Siemens Industrial Turbomachinery
	John Hald	Technical University of Denmark
	Masoud Rashidi	Chalmers
	Robert Lawitzki	Chalmers
	Hans-Olof Andrén	Chalmers
	Fang Liu	Chalmers
<i>Reference group:</i>	Bo Jönsson	Sandvik Heating Technology AB, Chalmers

International collaboration Z-ultra

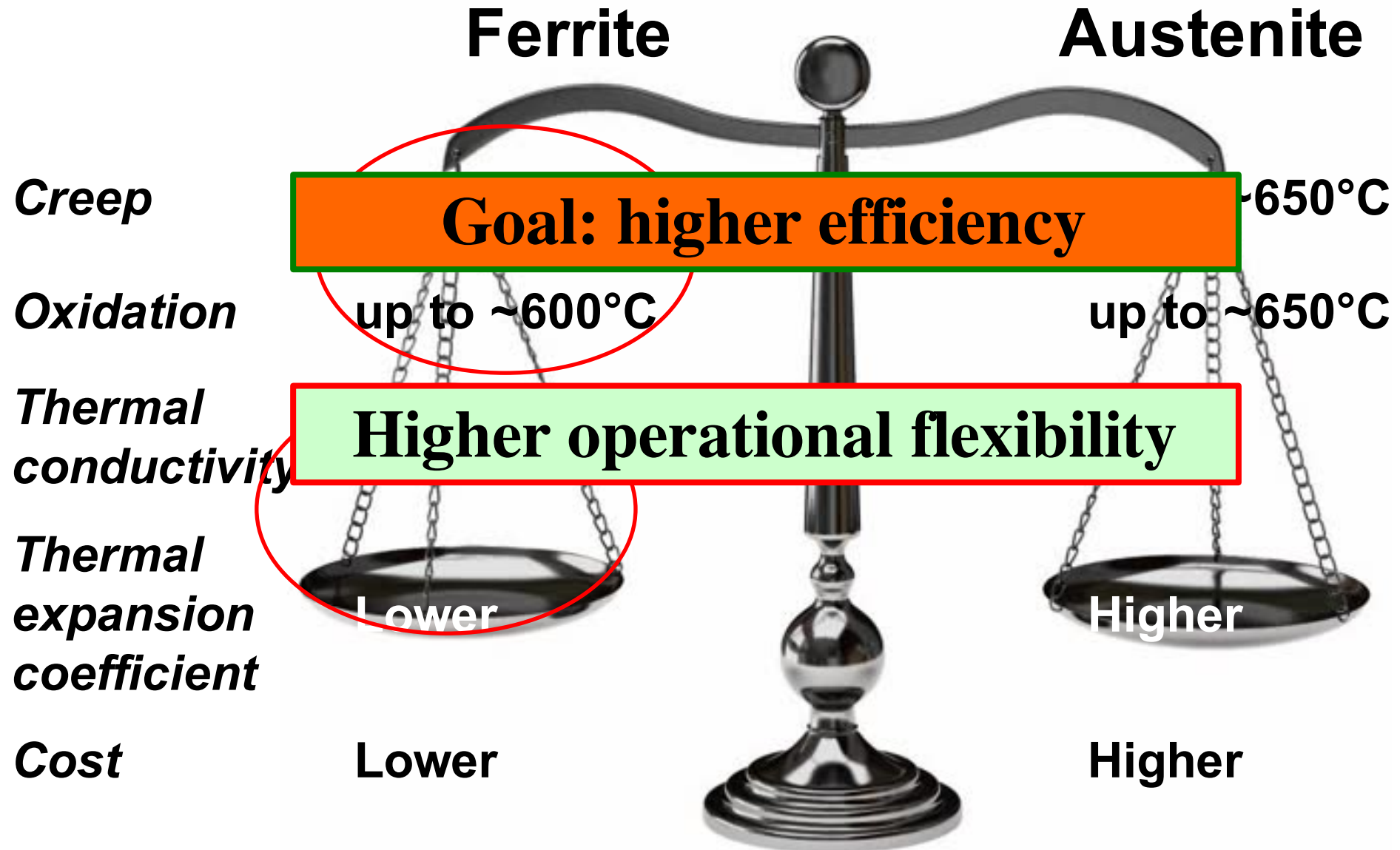


12% Cr steels in biomass thermal power plants

- Superheater tubes (with proper coating)
- Steam pipes
- Turbine house
- Turbine rotor
- Turbine blade

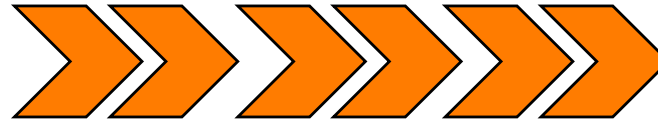


9–12% Cr steels VS. austenite



Better 9–12% Cr steels

Current status



Aim



600°C

9% Cr

Creep

Corrosion



650°C

9% Cr

Creep

Corrosion



650°C

12% Cr

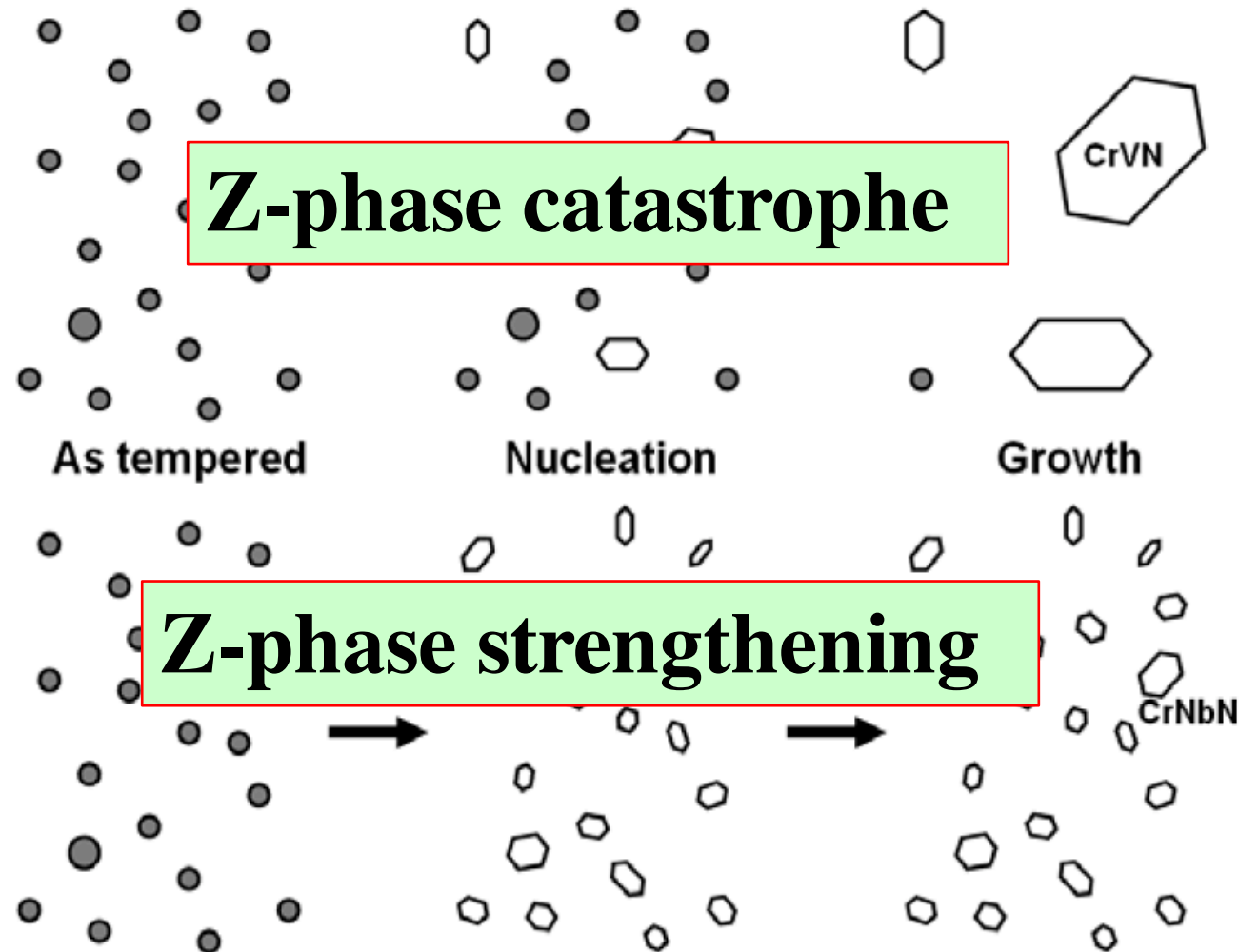
Creep

Corrosion

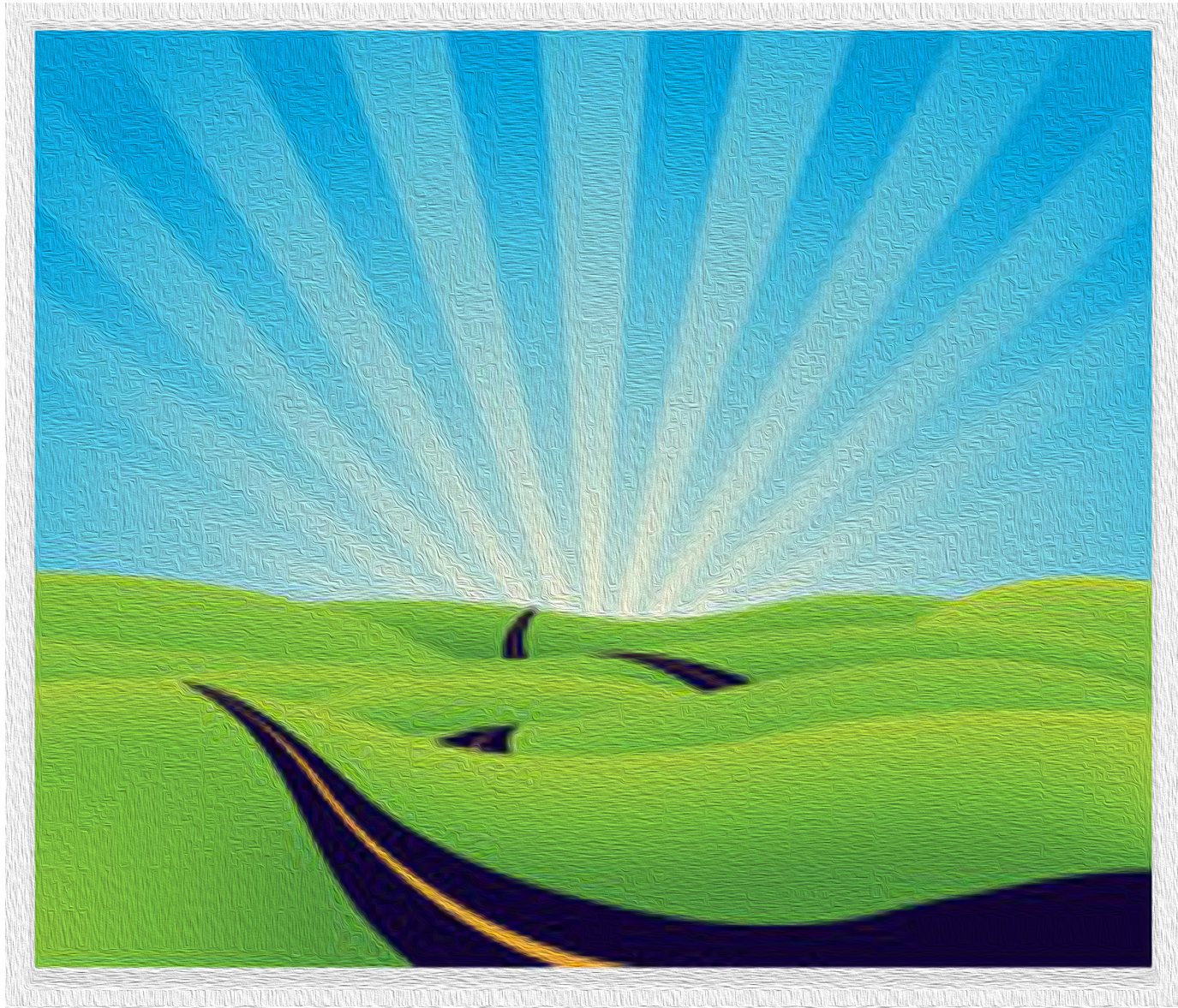




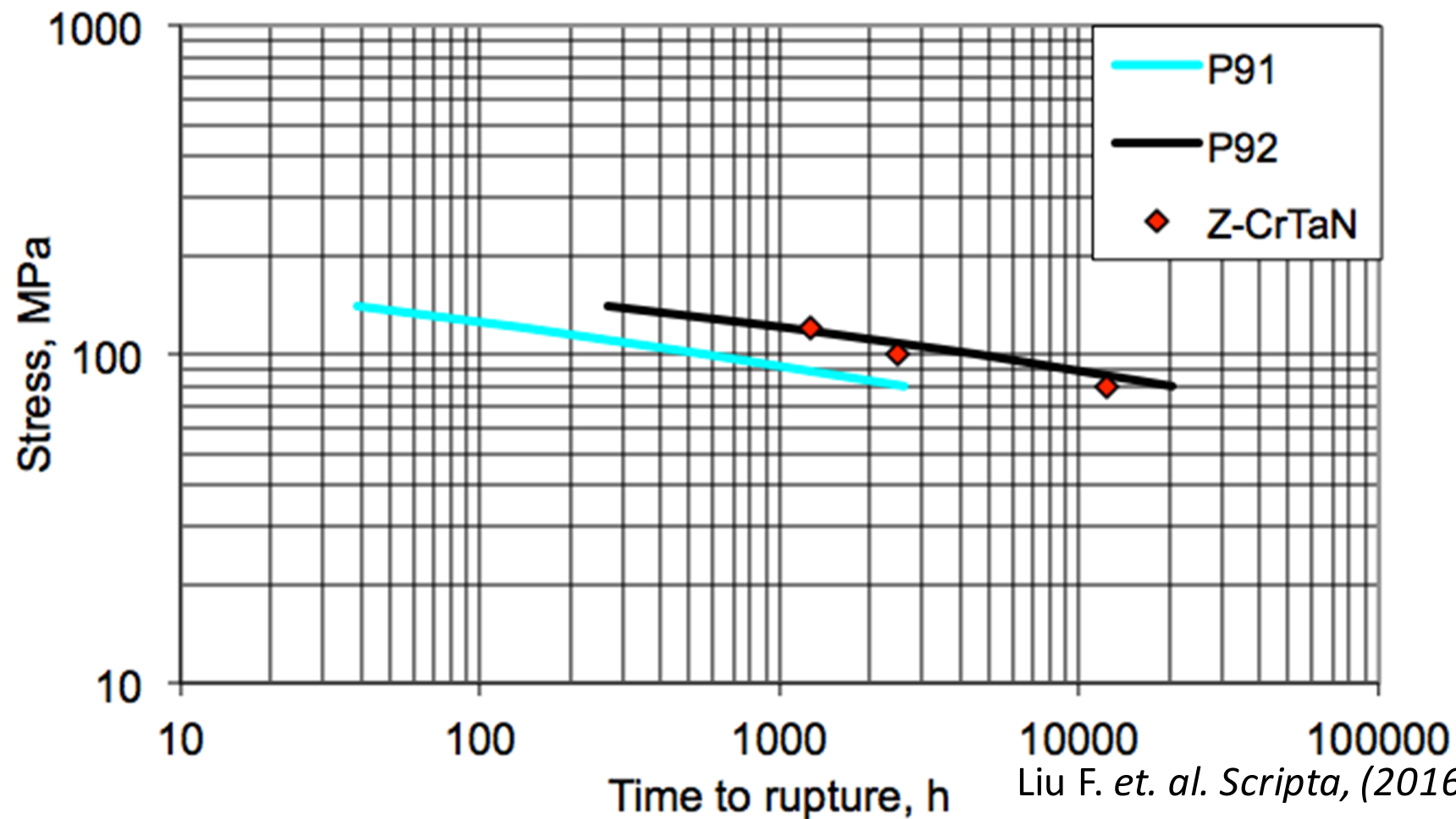
A new alloy design concept - Z-phase strengthened steels



Stage 1: proof of concept



Good creep strength at 650° C

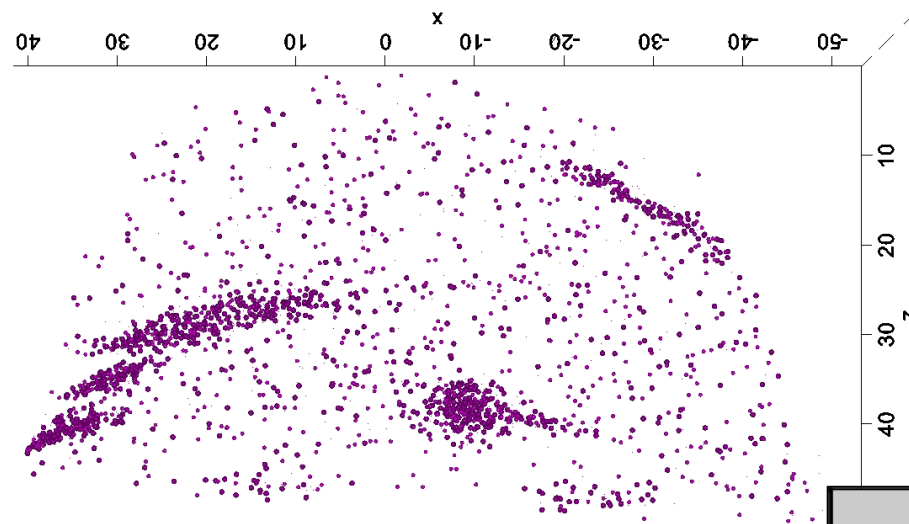


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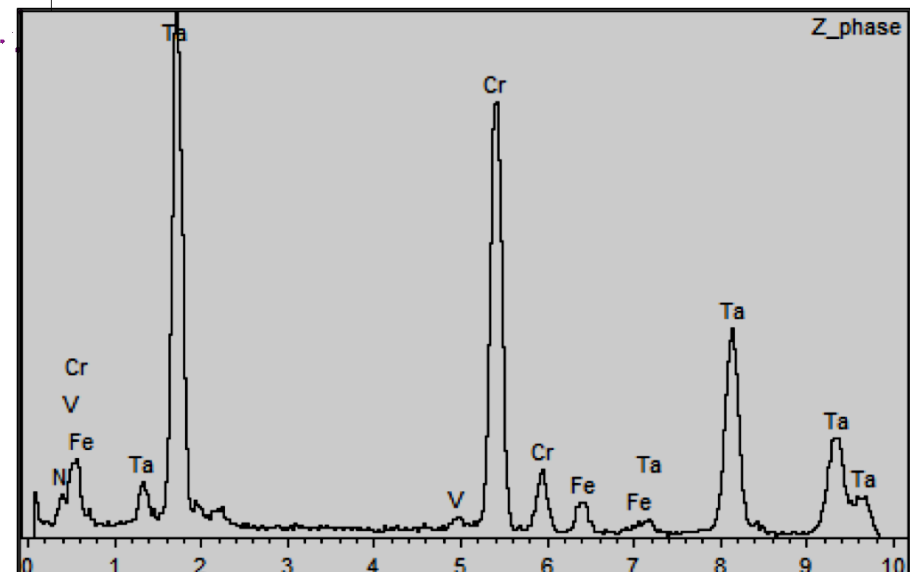
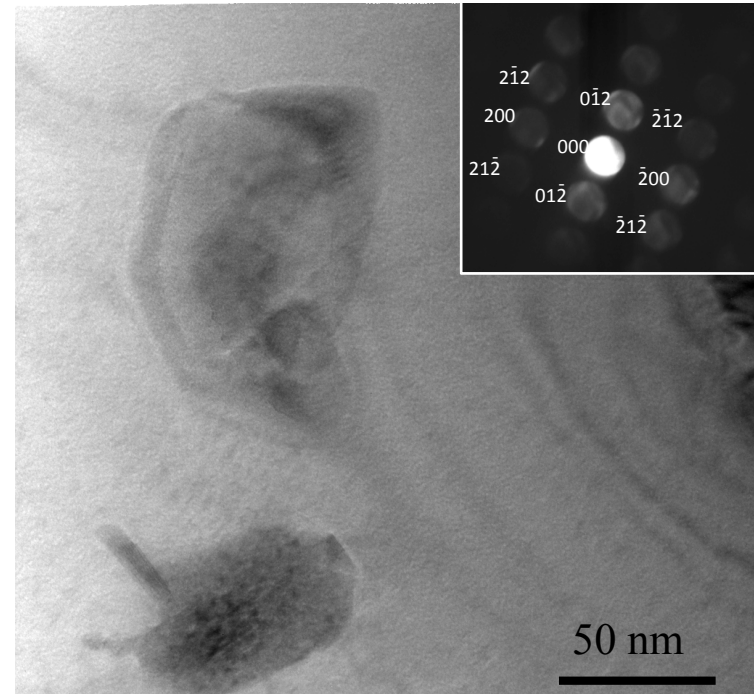
The creep property is comparable with the benchmark commercial steels P91 and P92.

Formation of Z-phase

Ta, TaN



$85 \times 85 \times 60 \text{ nm}^3$



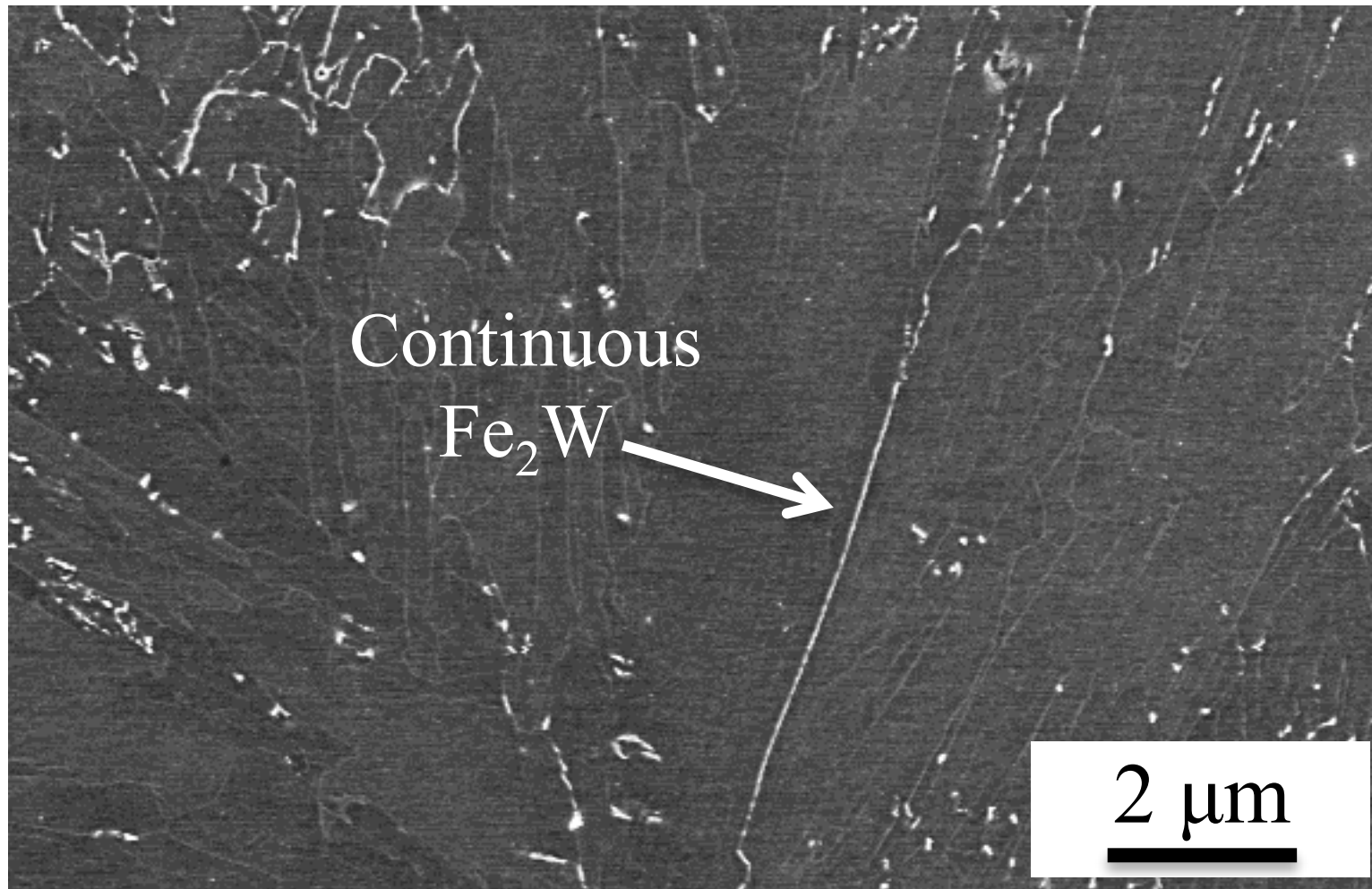
Poor room temperature toughness

Material	Rp0.2 (MPa)	Rm (MPa)	A5 (%)	Z (%)	Impact (J)
Z3	647	798	18.0	70.8	10.3
Z4	770	890	16.0	67.4	3.0

Stage 2: improve toughness



Continuous Laves phase along boundaries

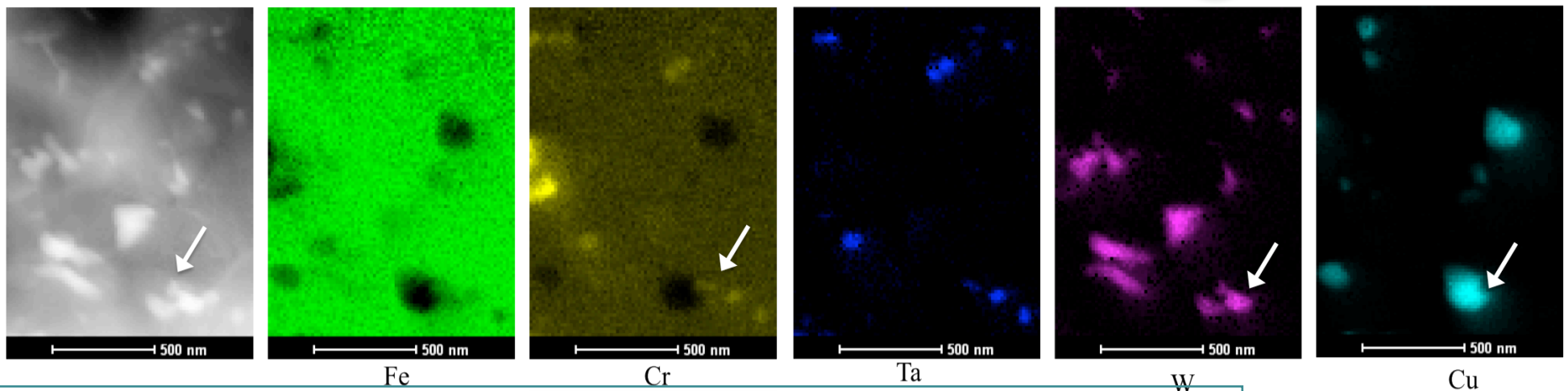


Laves phase (Fe_2W) along boundaries – reason for the poor toughness.

Control Laves phase morphology – Cu addition

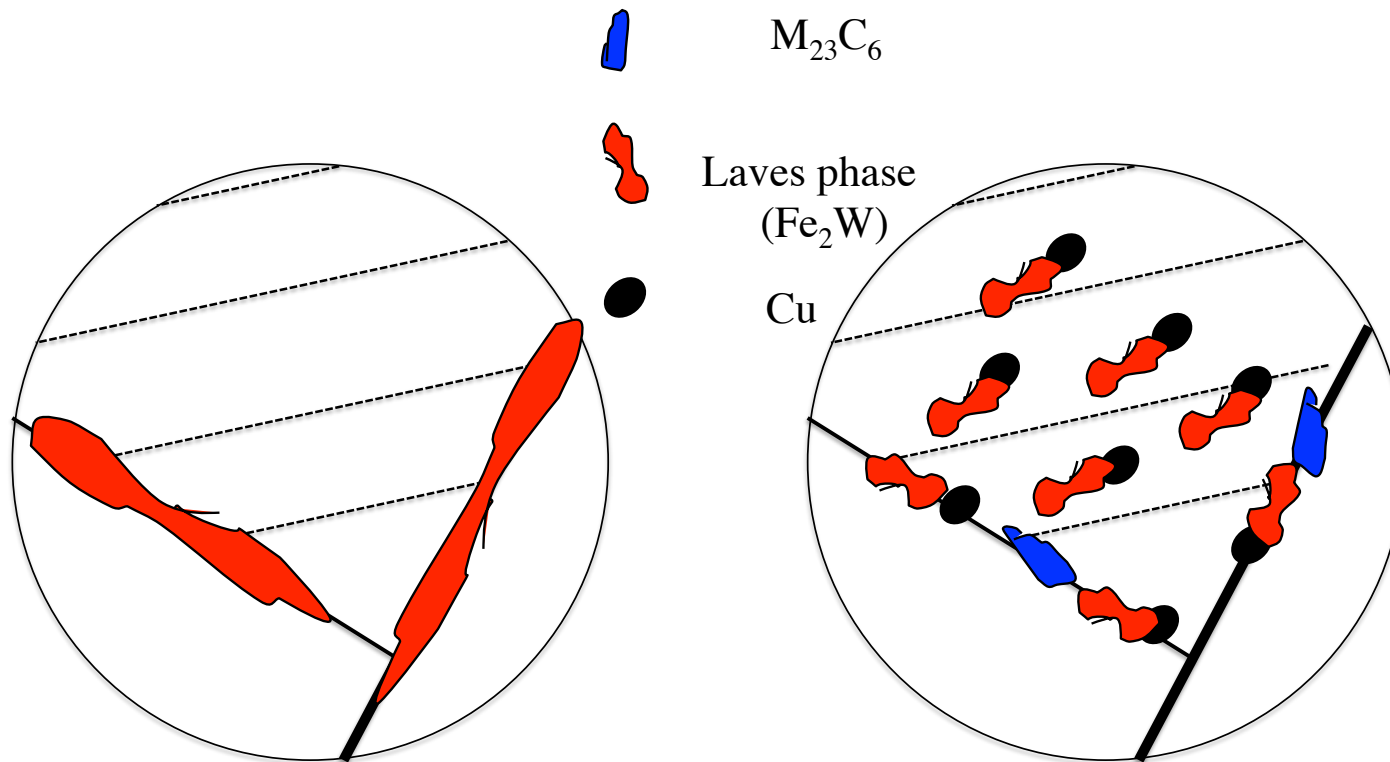
	Fe	Ni	Co	Cr	W	Ta	Cu	C	B	N	Si	Mn
Z4	bal.	0.48	7.01	12.84	0.89	0.12	–	0.02	0.02	0.13	0.60	0.49
ZL1	bal.	0.99	6.22	13.00	0.76	0.12	0.89	0.02	0.04	0.23	0.58	0.58

Material	Rp (MPa)	Rm (MPa)	A5 (%)	Z (%)	Impact (J)
Z3	647	798	18.0	70.8	10.3
Z4	770	890	16.0	67.4	3.0
ZL1	-	-	-	-	46.3



Modify Laves phase, improved toughness.

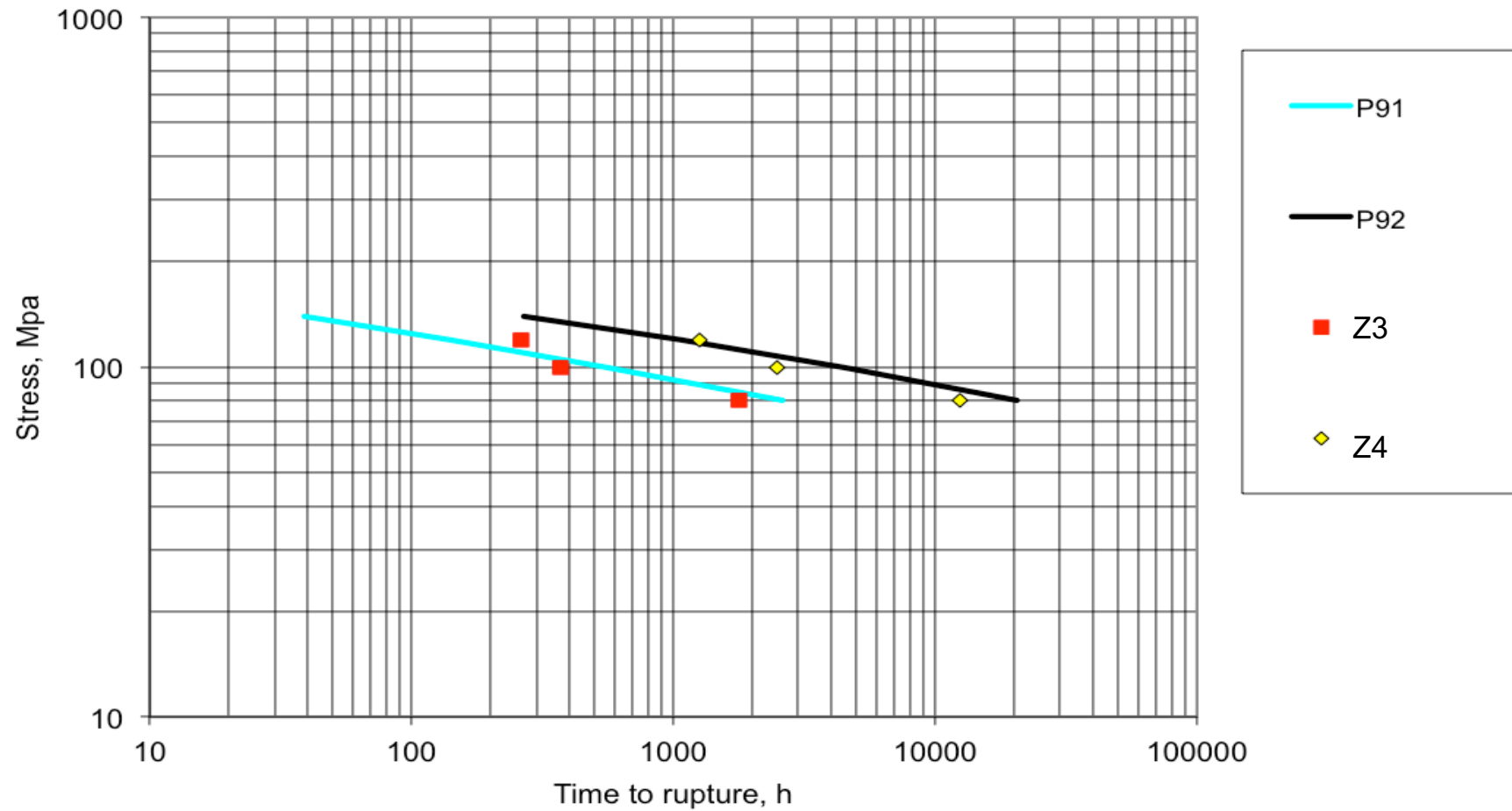
Control Laves-phase morphology



Stage 3: Optimize chemical composition



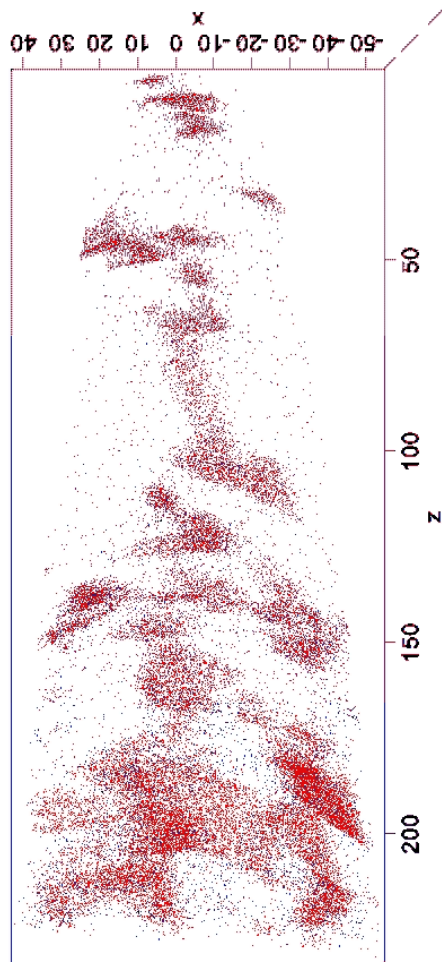
Nb VS. Ta



The Ta-containing steel is better than the Nb-containing one.

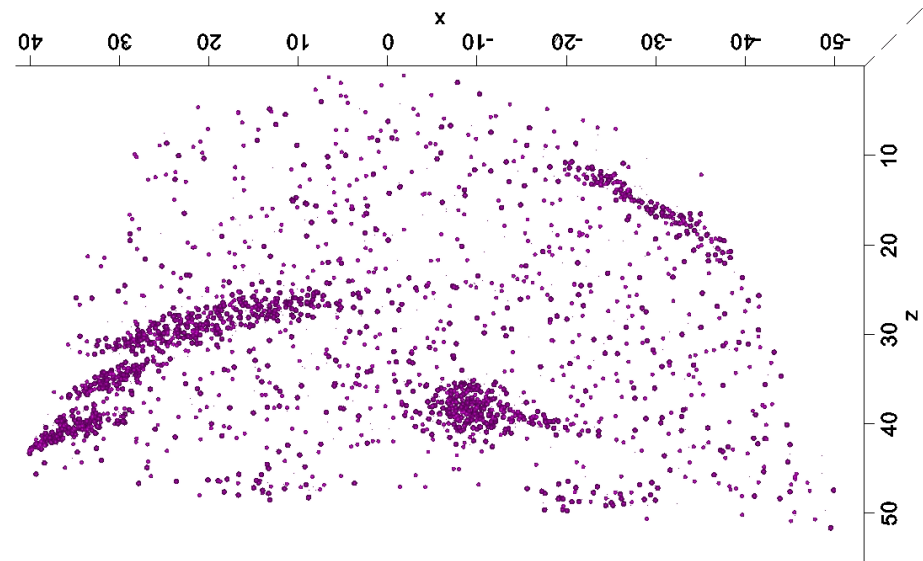
Nb VS. Ta

Nb, NbN



$110 \times 110 \times 235 \text{ nm}^3$

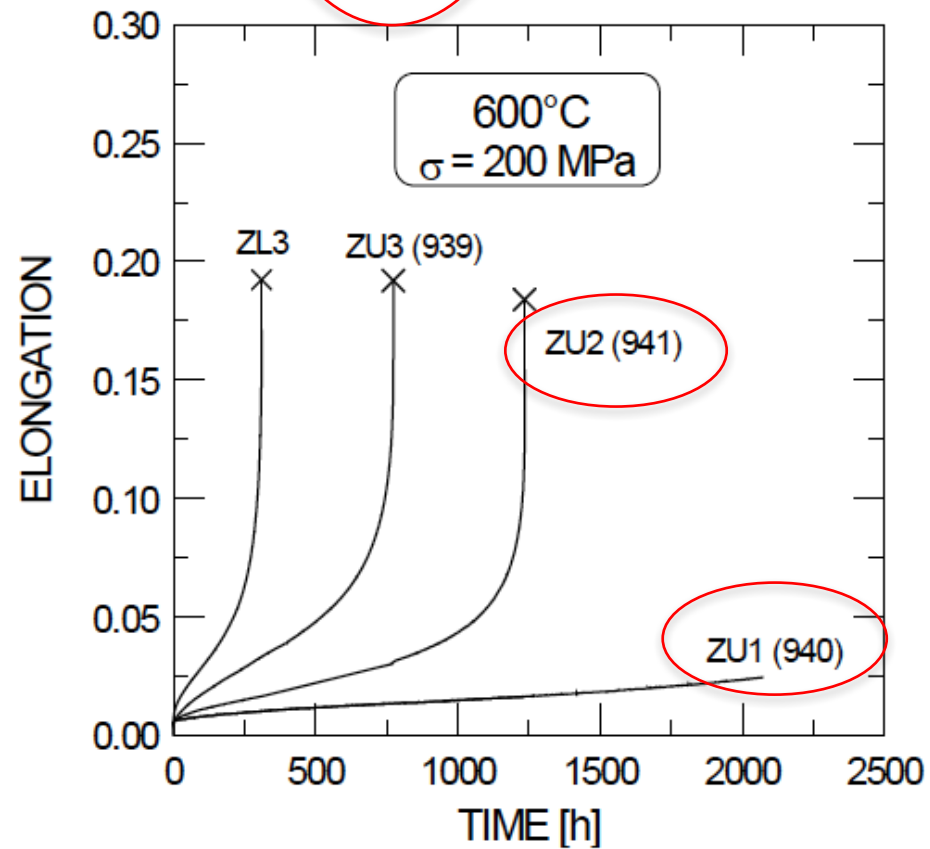
Ta, TaN



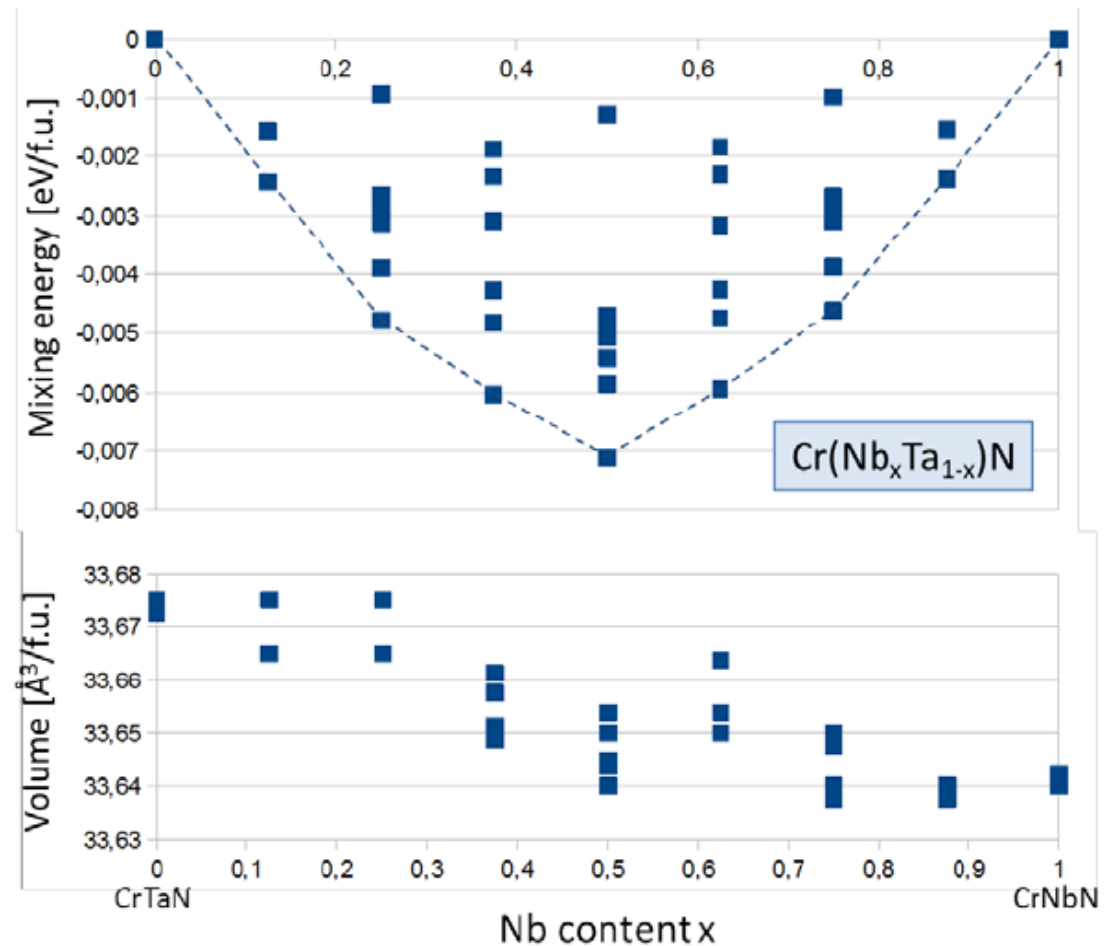
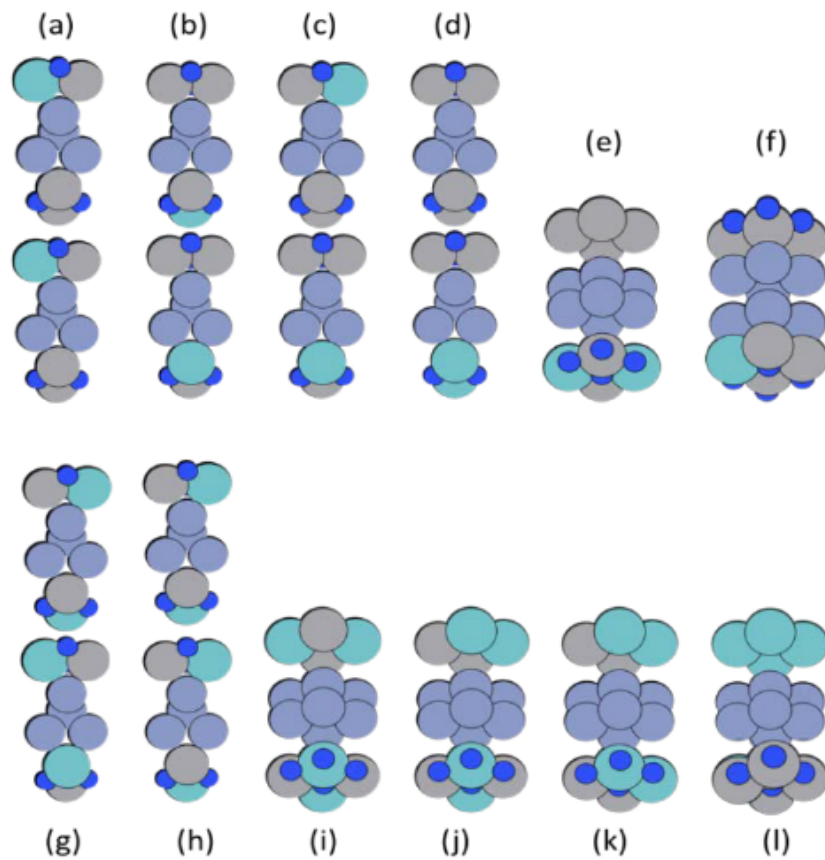
$85 \times 85 \times 60 \text{ nm}^3$

Nb + Ta -> ?

Steel	Ni	Co	Cr	W	Nb	Ta	C	B	N	Si	Mn	Cu	Mo
ZU1	0.17	2.67	12.10	0.61	-	0.11	0.13	0.02	0.18	0.68	0.12	1.77	-
ZU2	0.16	3.05	12.11	0.64	0.10	0.06	0.14	0.03	0.17	0.64	0.13	1.86	-

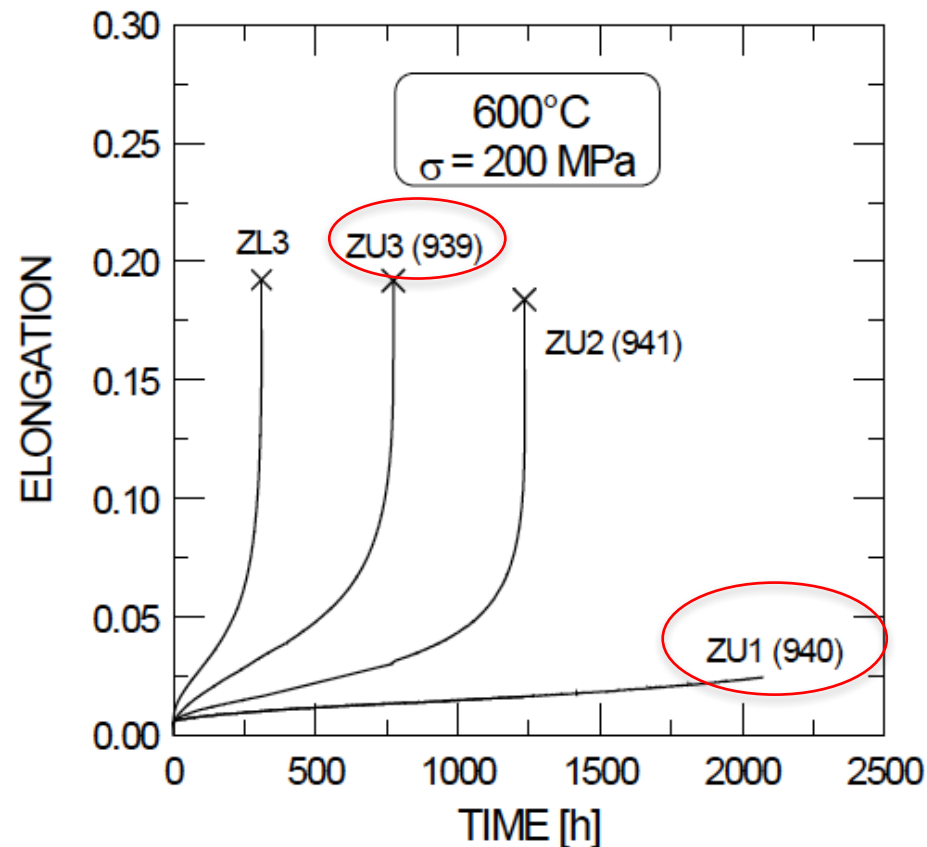


DFT modeling on mixing of Ta and Nb



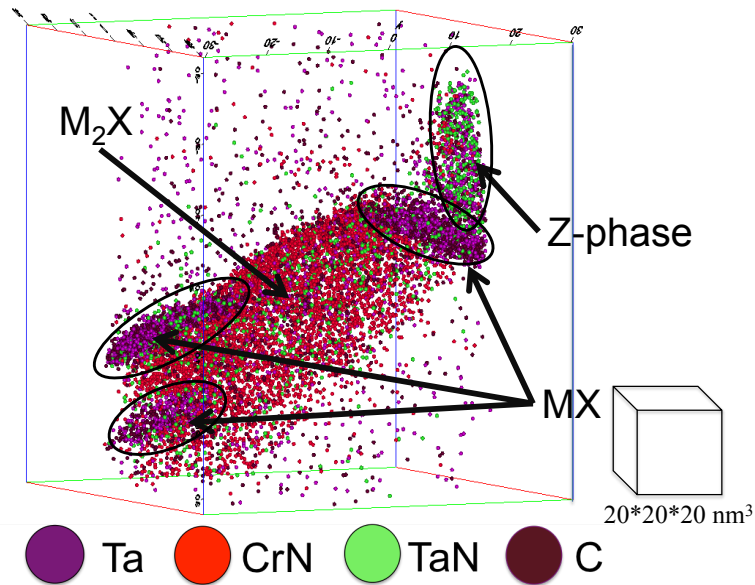
Effects of carbon concentration

Steel	Ni	Co	Cr	W	Nb	Ta	C	B	N	Si	Mn	Cu	Mo
ZU1	0.17	2.67	12.10	0.61	-	0.11	0.13	0.02	0.18	0.68	0.12	1.77	-
ZU2	0.16	3.05	12.11	0.64	0.10	0.06	0.14	0.03	0.17	0.64	0.13	1.86	-
ZU3	0.20	3.00	12.18	0.56	-	0.14	0.24	0.02	0.15	0.47	0.12	-	0.30

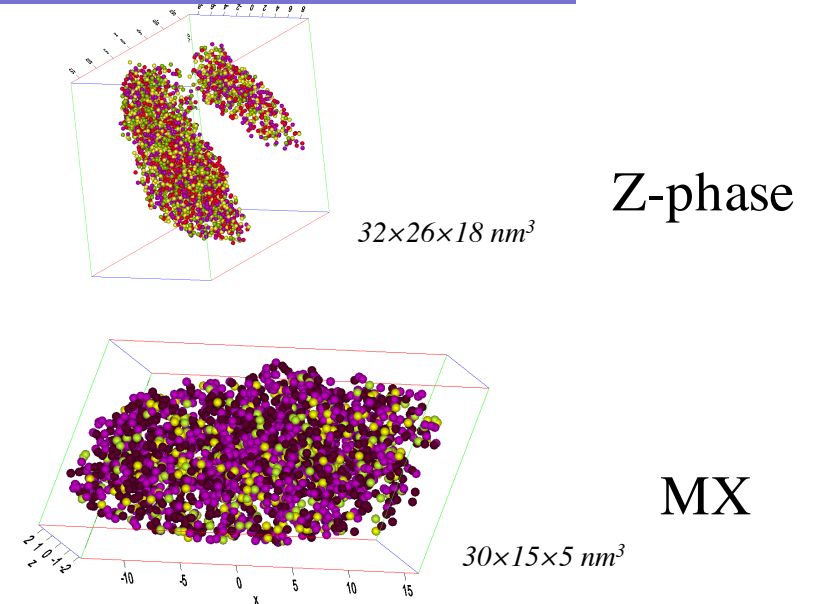


Effects of carbon concentration – transformation from MX to Z-phase

as-tempered



1000 hours aged at 650°C



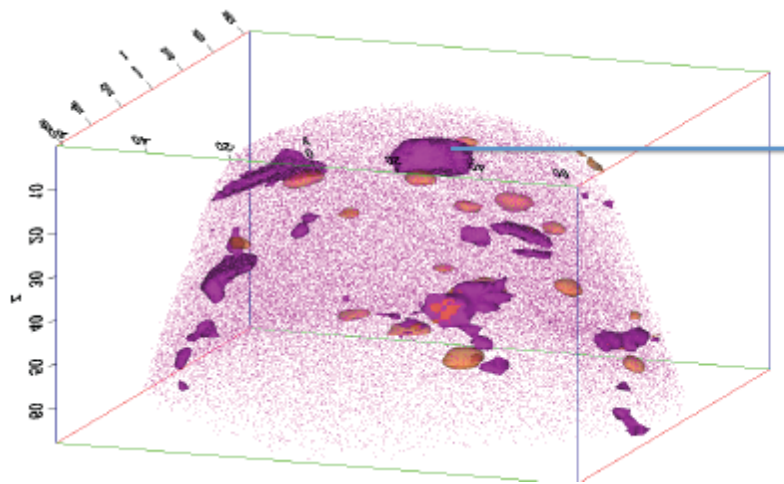
	Cr	Ta	N	C	B	V	Fe
Ta(C, N)	13.1	38.1	16.7	25.9	-	-	4.2
Z-phase	36.6	25.1	24.8	2.4	0.7	0.7	9.1

	Cr	Ta	N	C	B	V	Fe
Ta(C, N)	4.7	50.0	11.8	29.4	-	0.7	2.7
Z-phase	40.8	25.8	24.5	0.6	-	0.8	7.0

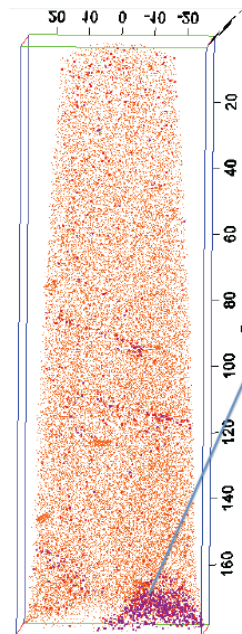
High C concentration, slow Z-phase formation

Effects of carbon concentration – New pathway of Z-phase transformation?

	C	Mn	Si	Cr	Ni	Mo	W	Co	Cu	B ppm	N	Ta
ZU4	0.015	0.086	0.29	11.49	0.11	0.006	2.01	3.91	2.00	25	0.045	0.37
ZU5	0.013	0.090	0.28	11.45	0.10	0.005	2.47	5.65	1.02	26	0.043	0.40
ZU6	0.012	0.097	0.30	11.34	0.08	0.006	2.31	5.11	2.01	42	0.042	0.40
ZU7	0.008	0.093	0.30	11.29	0.10	0.005	2.69	5.60	1.53	25	0.040	0.43



ZU4

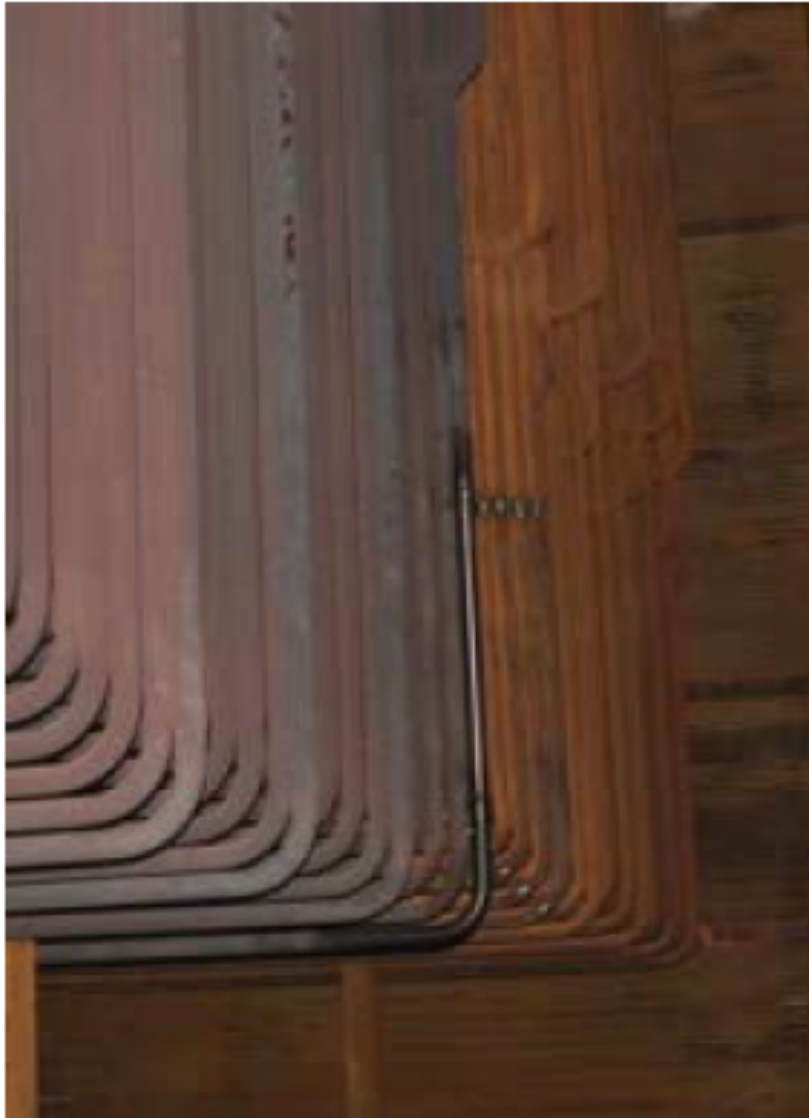


ZU7

Cr	N	Ta	Fe	C
34	28	20	10	1.3



Demonstration tubes in power plants of Kievenergo (IPP center in **Ukraine)**_h



Since September 2014

Summary

- Z-phase strengthening 12% Cr is feasible.
- 4 series, 14 testing alloys have been designed and produced.
- Continuous Laves-phase formation impairs impact strength.
- Laves phase morphology can be controlled, by Cu and C addition, thus improving the impact strength.
- C addition has a profound impact on the transformation from MX to Z-phase

Ongoing work and future plan

- Collaboration with modeling efforts
 - e.g. understand the effects of C.
- Further alloy design fine tuning.
 - e.g. optimize C/N.
- Field testing of new steels in power plants.

Thank you for your attention!

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