Computer Aided Design of Advanced Turbine Airfoil Alloys for Industrial Gas Turbines in Coal Fired Environments

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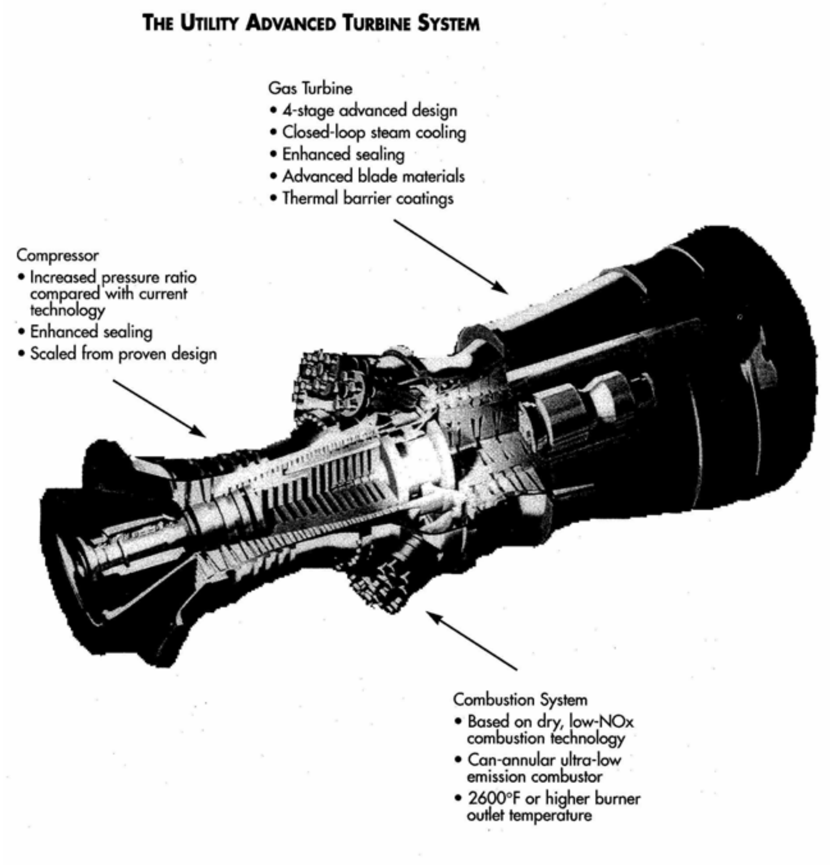
Gas Turbine - Power Generation



*Why Are We **STILL** Studying Ni-base Superalloys?*

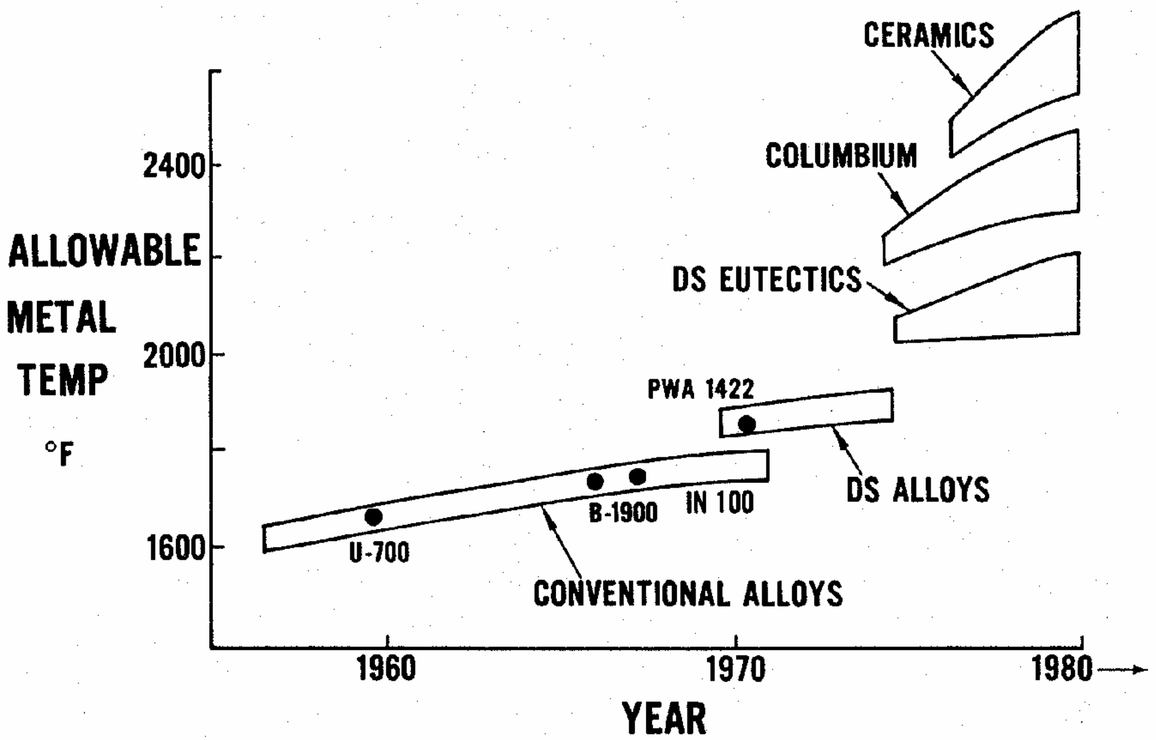
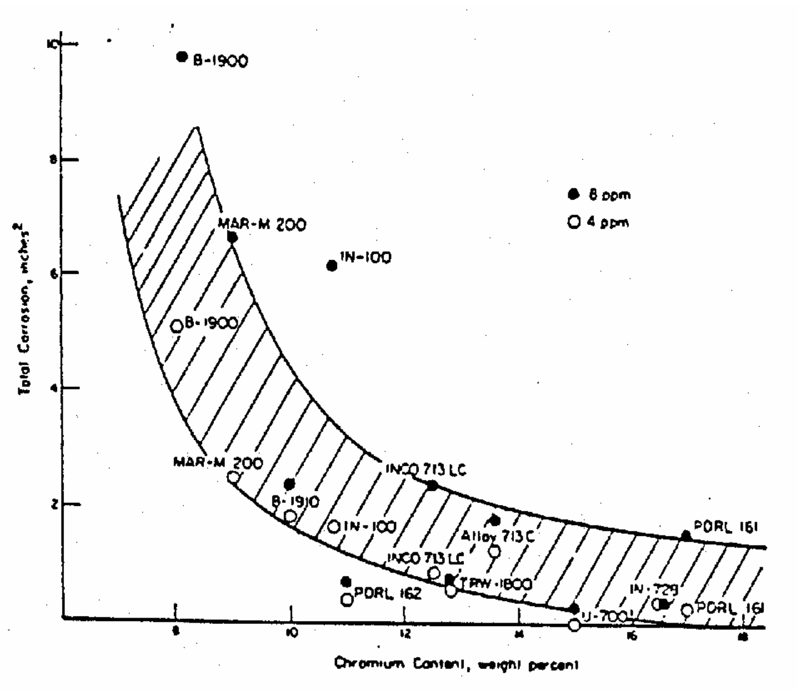


Fig. 4.15 Trends in turbine airfoil materials

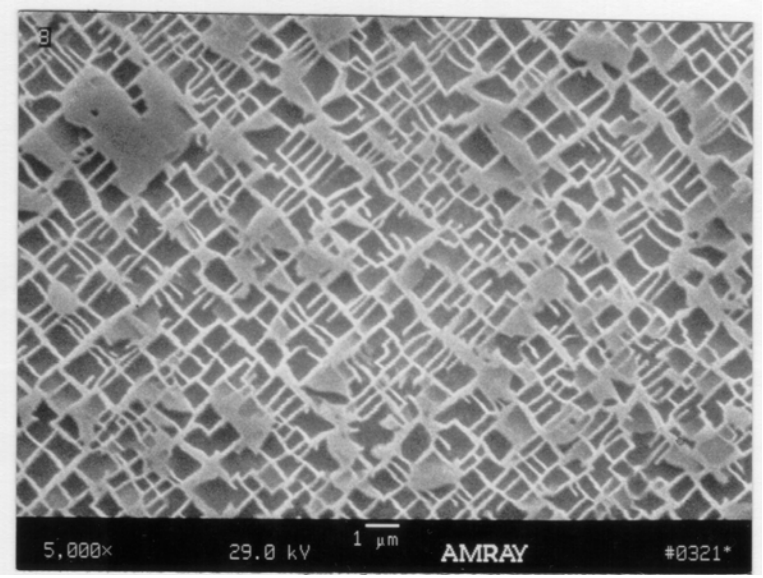
Aero vs IGT Compositions

- Significantly different compositions
  - strength
  - temperature
  - environment
- Consider each alloy addition separately
  - CMSX-4 baseline

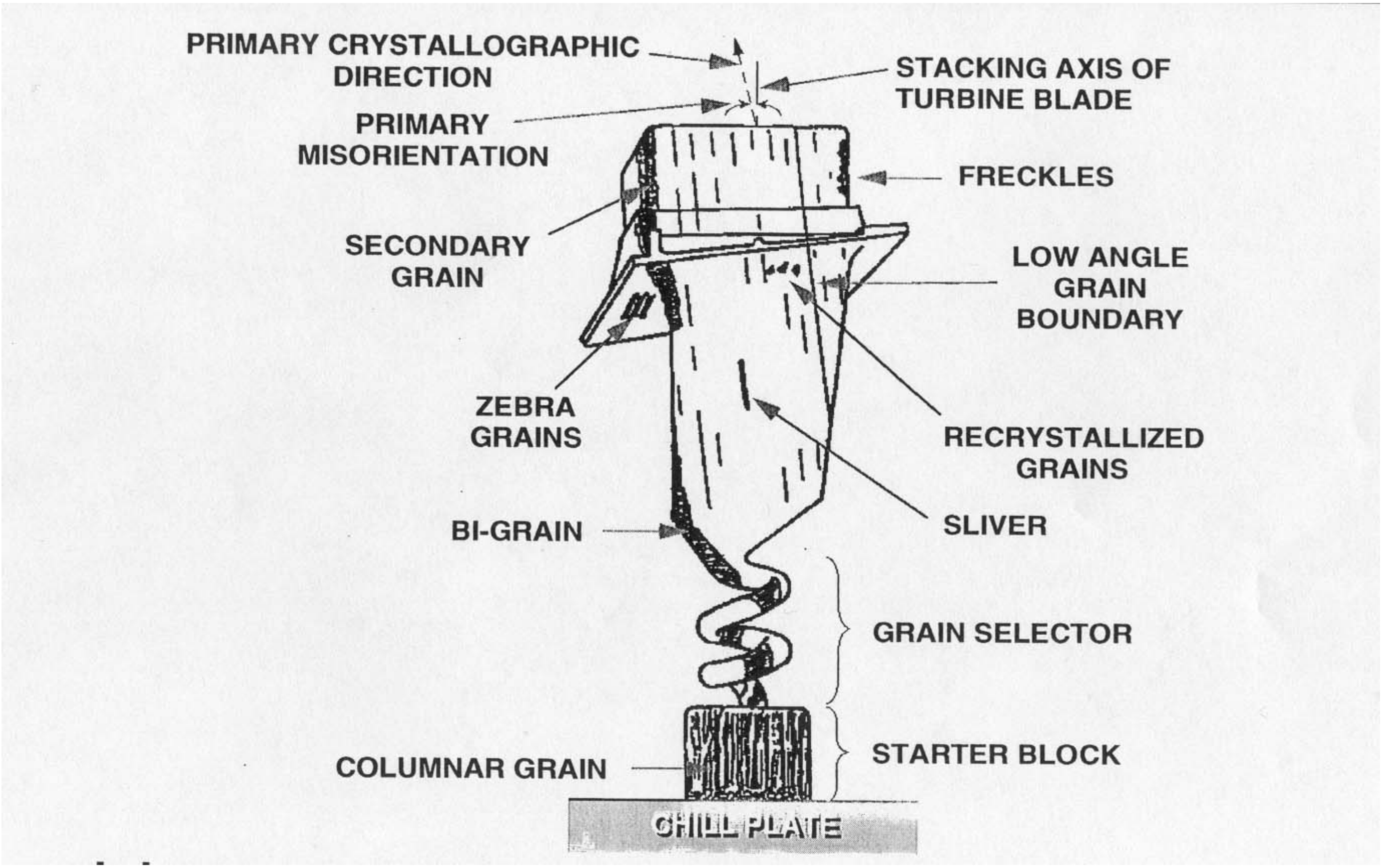


Ni-base Superalloys

- Ni-base superalloys consists of at least 12-13 elements added or controlled to get the best combination of properties.
  - Ni, Al, Cr, Co, Mo, W, Re, Ta, Ti, Nb, Hf, C, …….
- Ni-base superalloy microstructure:
  - γ phase (FCC)
  - γ' ($L1_2$) precipitates (50-70 vol%)
    - coherent with γ phase
    - $Ni_3(Al,Ti,Ta,Nb)$.
  - Carbides
    - Primary MC-type
    - Secondary
  - TCP phases



Castability for IGT Components



Alloy Compositions (wt%)

Alloy	Ni	Cr	Co	Mo	W	Re	Al	Ti	Ta	Hf	C, ppm	B, ppm	Other
CMSX-2	Bal	8.0	5.0	0.6	8.0		5.6	1.0	6.0				
CMSX-3	Bal	8.0	5.0	0.6	8.0		5.6	1.0	6.0	0.1			
Rene' N4	Bal	9.0	8.0	2.0	6.0		3.7	4.2	4.0	0.15	0.05	0.004	0.5Nb
PWA 1480	Bal	10.0	5.0		4.0		5.0	1.5	12.0				
CMSX-4	Bal	6.4	9.7	0.6	6.4	3	5.65	1.0	6.5	0.1	<30		
Rene' N5	Bal	7.0	7.5	1.5	5.0	3	6.2		6.5	0.15	500	40	
PWA 1484	Bal	5.0	10.0	2.0	6.0	3	5.6		8.7	0.1			
PWA 1483	Bal	12.8	9.0	1.9	3.8		3.6	4.0	4.0		0.07		
ABB (5,888,451)	Bal	6.5	9.5	0.6	6.4	3	5.6	0.6	7.5	0.2	250	50	0.002Mg
ABB (5,759,301)	Bal	6.3	9.5	0.6	6.6	3	5.7	0.8	6.7	0.25	250	50	0.002Mg
SC CM186LC	Bal	6.0	9.0	0.5	8.0	3	5.7	0.7	3.0	1.4	700	150	0.005Zr
CMSX-11B	Bal	12.5	7.0	0.5	5.0		3.6	4.2	5.0	0.04			0.1Nb
CMSX-11C	Bal	14.9	3.0	0.4	4.5		3.4	4.2	5.0	0.04			0.1Nb
LMSX-10	Bal	4.1	12.2		5.85	3	5.55		8.6	0.10			
SC130	Bal	5.0	10.5	2.0	5.0	3	5.5	1.5	6.3				

Current Work

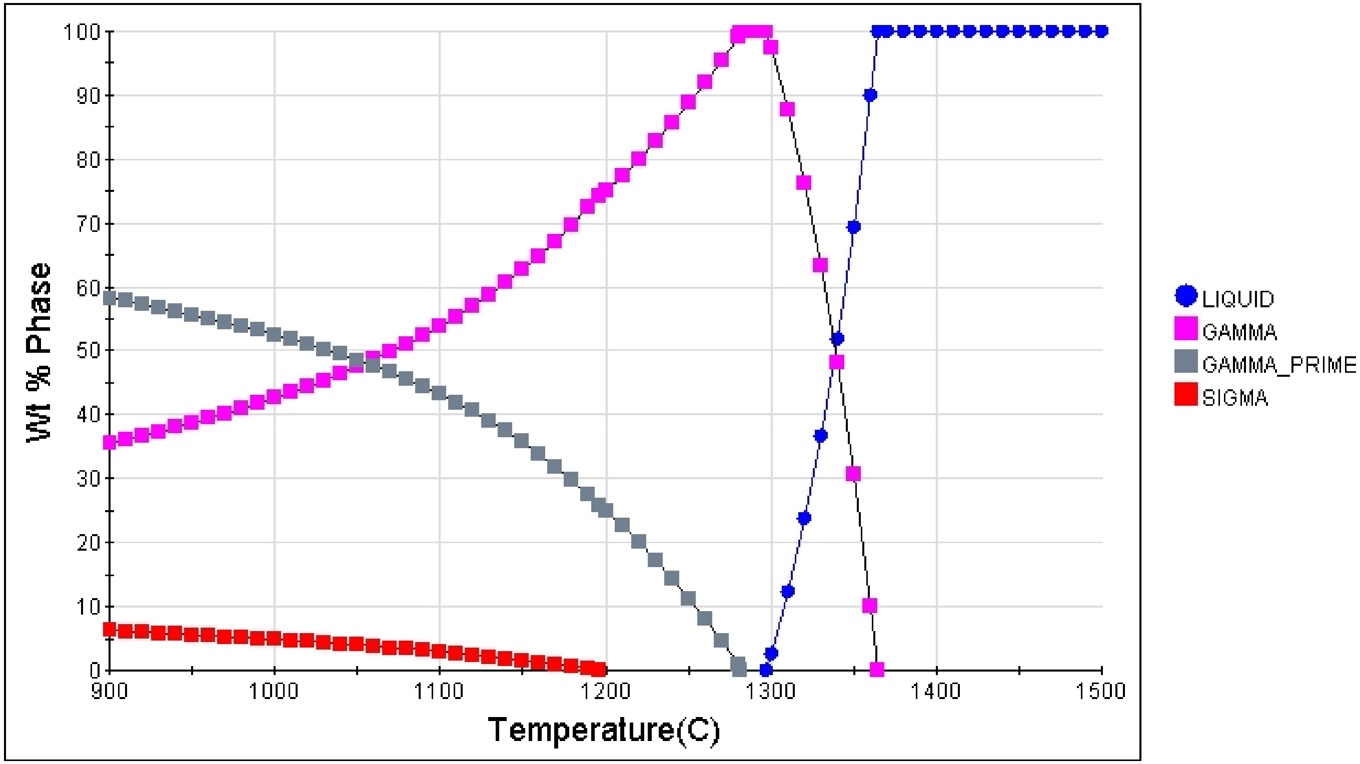
- Utilized JMatPro to identify potential compositions for IGT alloy
  - Computational work performed at Siemens
  - 2 iterations, with collaboration from industry
  - Final iteration with experimental verification using 50g button melts.
- Examined effect of C, C+B and C+N to CMSX-4
  - Carbon effects on solidification defects
  - C+B for defect tolerance
  - C+N effect on carbide composition and solvus
  - CMSX-4 master alloy provided by Cannon Muskegon
  - SX bars processed at PCC Airfoils

Current Work

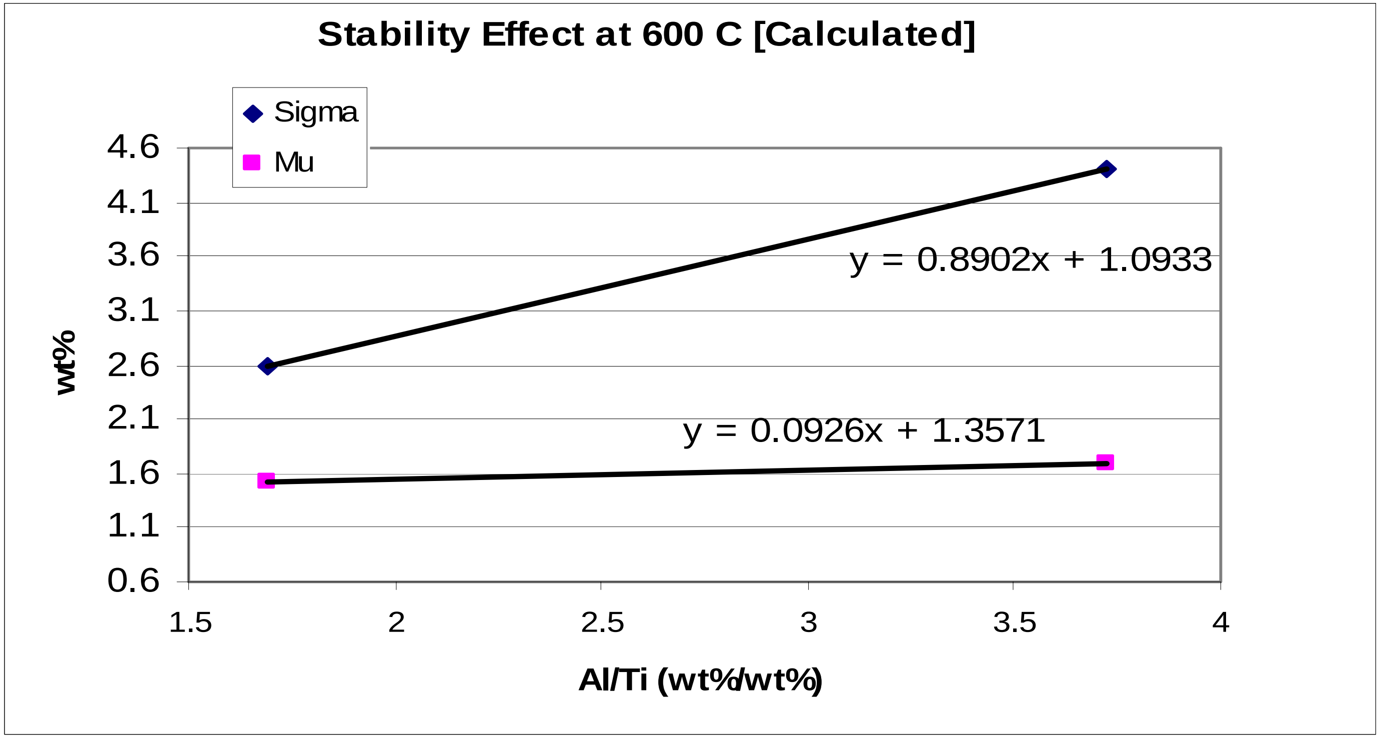
- JMatPro used to identify trends in alloying
  - Solidus, liquidus, γ'-solvus, TCP, segregation
  - Vary composition at three levels
- 50g button melt
  - As-cast microstructure characterized
    - Segregation
  - DTA
    - Solidus, liquidus and γ'-solvus
- Compare JMatPro predictions to experimental results
- Identify alloy(s) that may be suitable for IGT

JMatPro Results

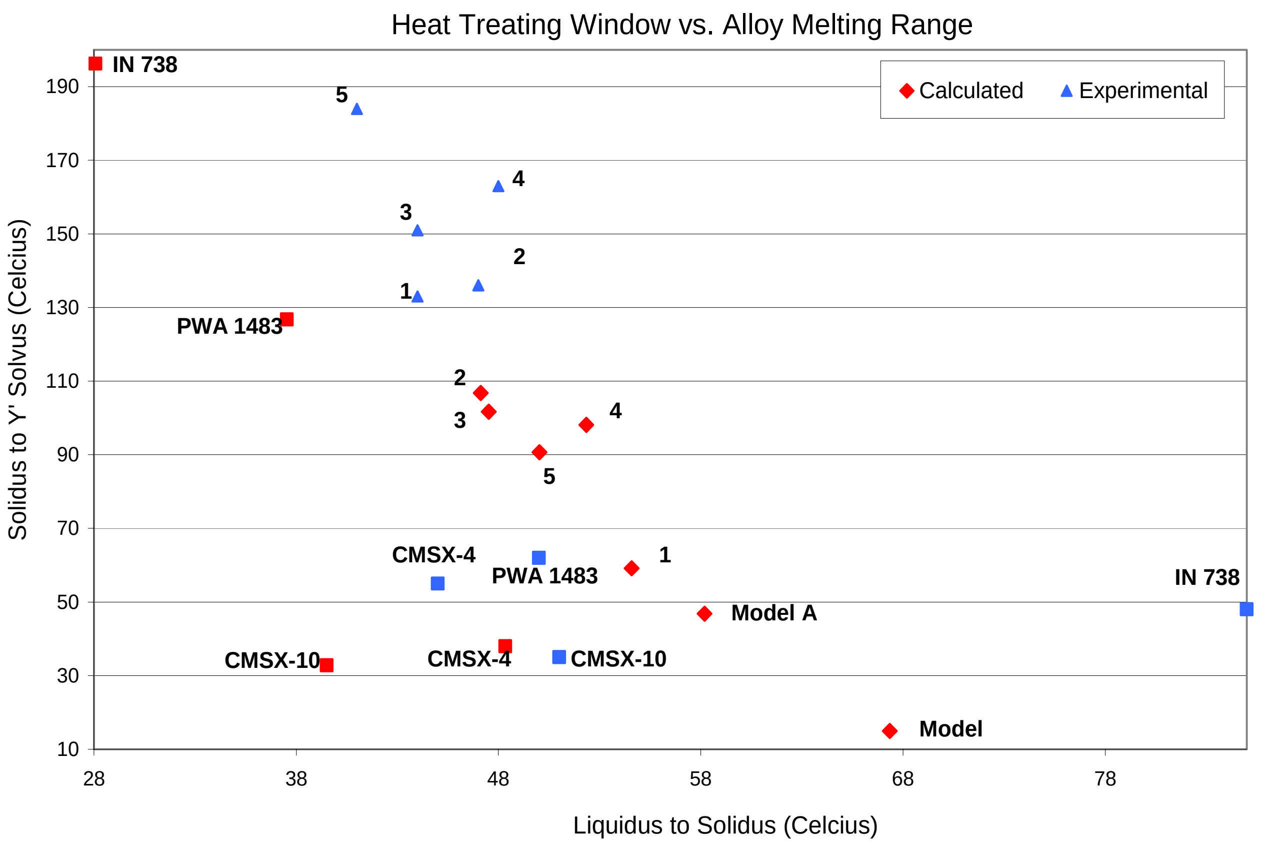
Ni-12.0Al-12.0Co-12.0Cr-0.05Hf-1.0Re-3.0Ta-2.0W at(%)



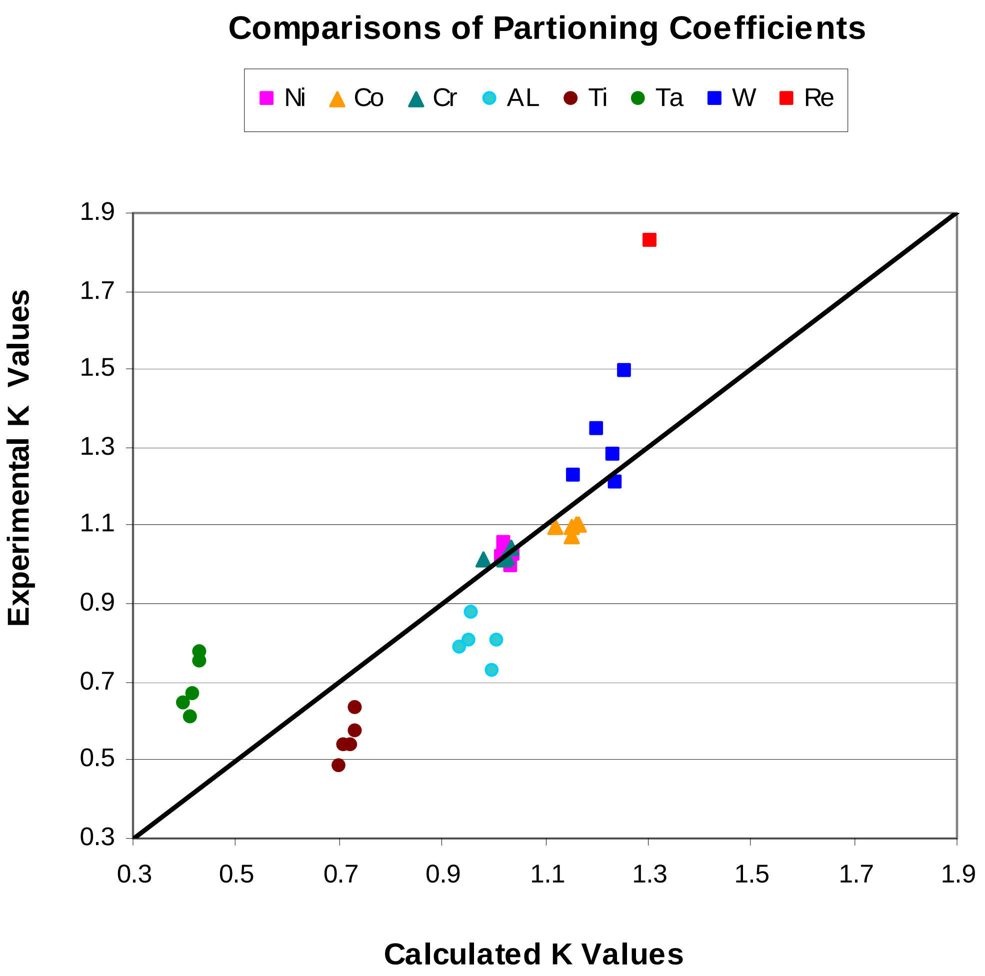
Predicted Stability



Predicted Phase Transformation Temperatures



Segregation Behavior

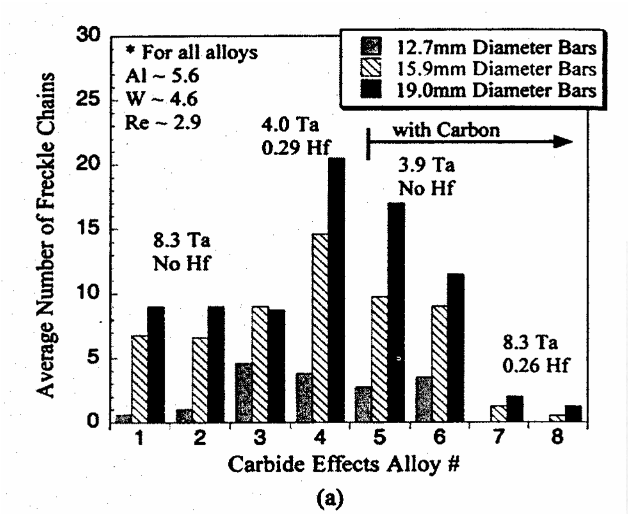


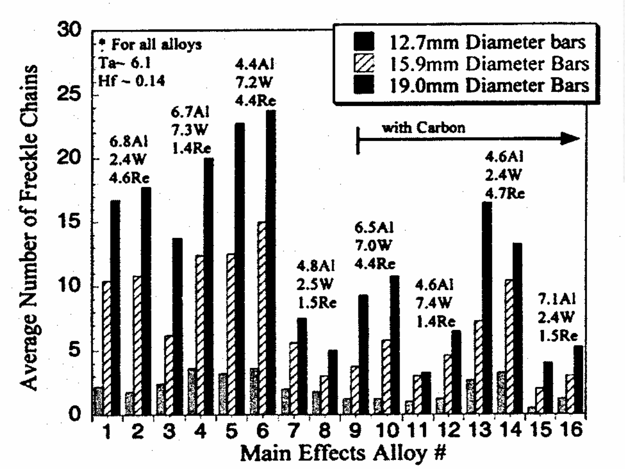
Summary of Current Work

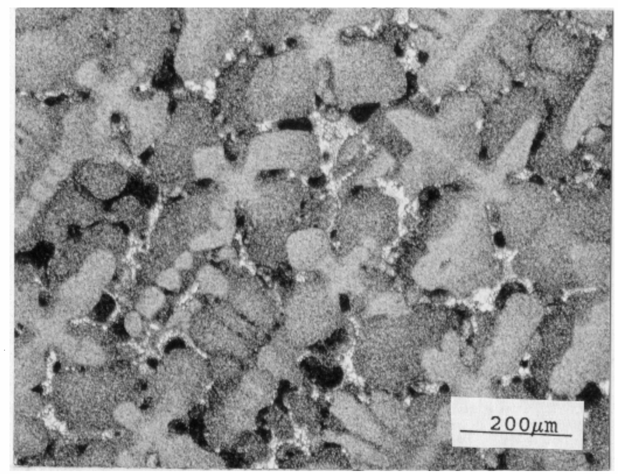
		Ni	Al	Co	Cr	Hf	Re	Ta	W	Ti	C	Al/Ti	Y' at%
Alloy 1	wt %	57.54	4.37	11	11	0.1	0	8.8	5.96	1.17	0.05	3.72	14.5
	at %	58.71	10	11.5	13	0.03	0	3	2	1.5	0.26		

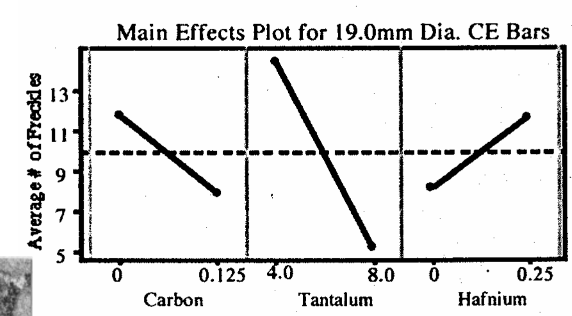
- Utilized a baseline alloy
- Developed 50 alloy compositions of interest
- Discussed all compositions with industrial collaborators
- Identified a composition that may be suitable for IGT
  - Heat of Alloy 1 to be processed at PCC Airfoils

Castability and C Additions



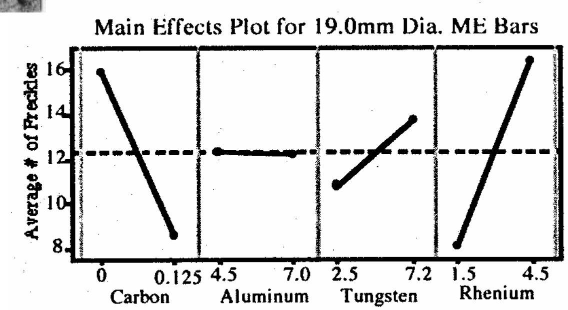




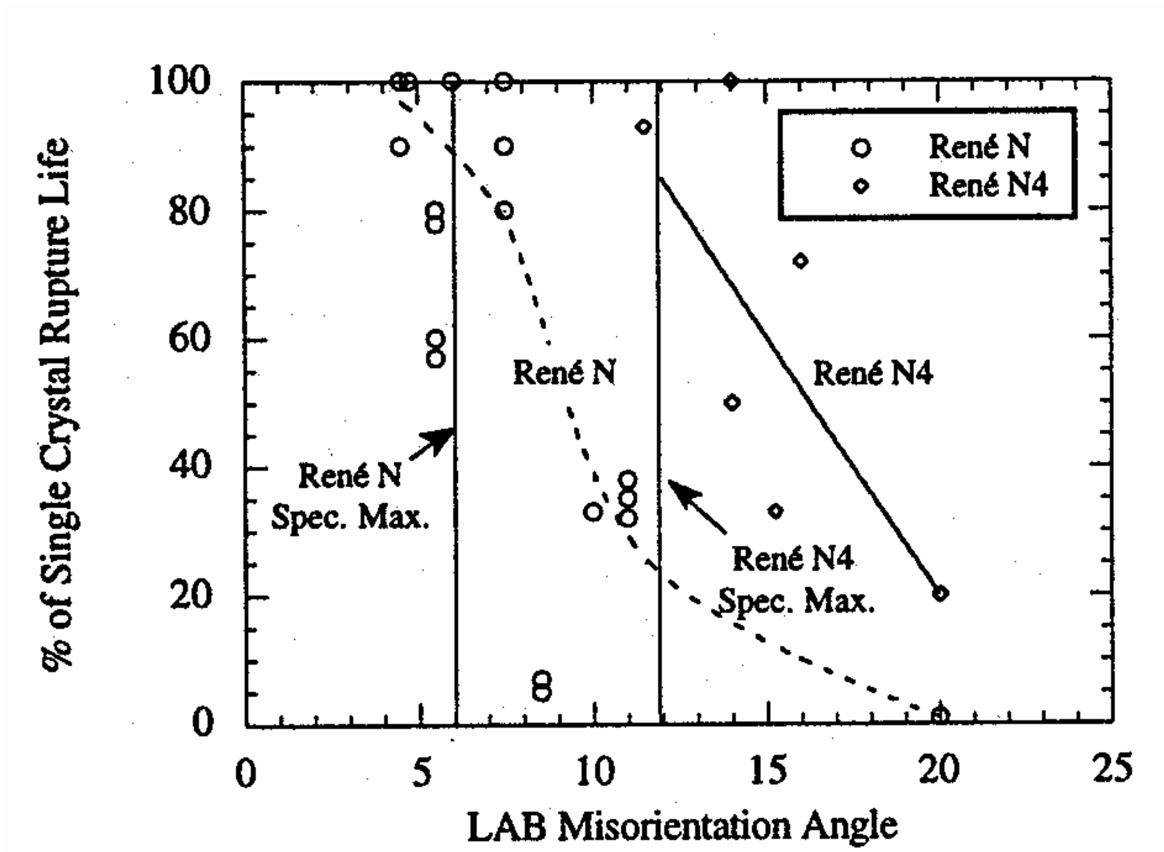


Rayleigh's solute number:

$$R_s = [g\beta\Phi/9r^2\eta m_L D](K/GR)$$

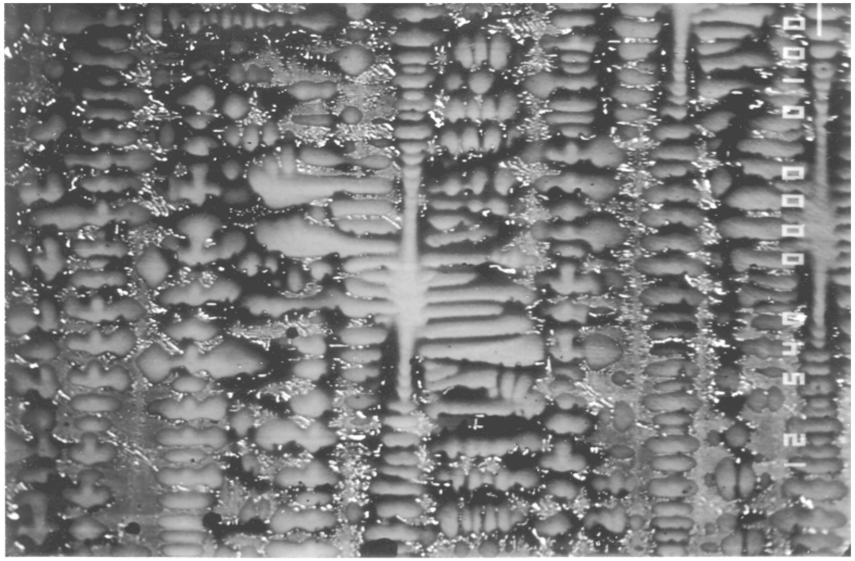


Effect of C and B on Properties

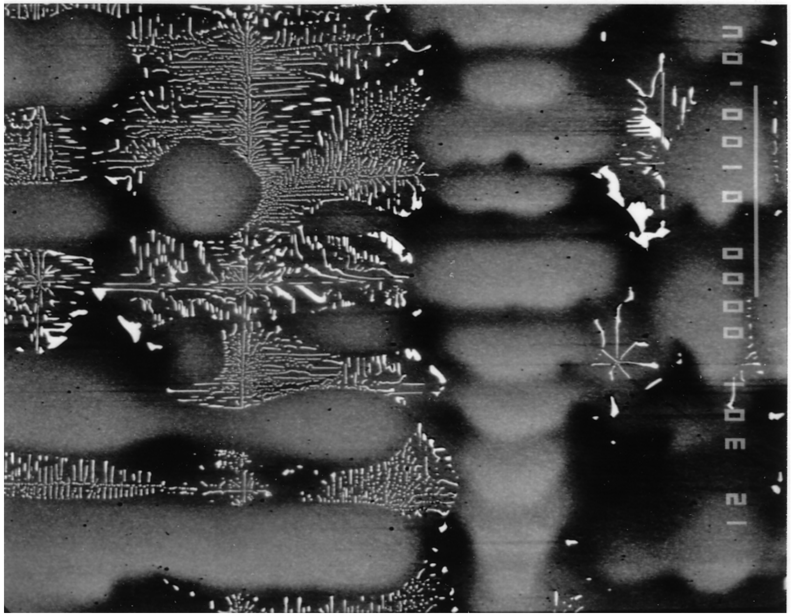


Carbides

- Longitudinal Sections (BSE).



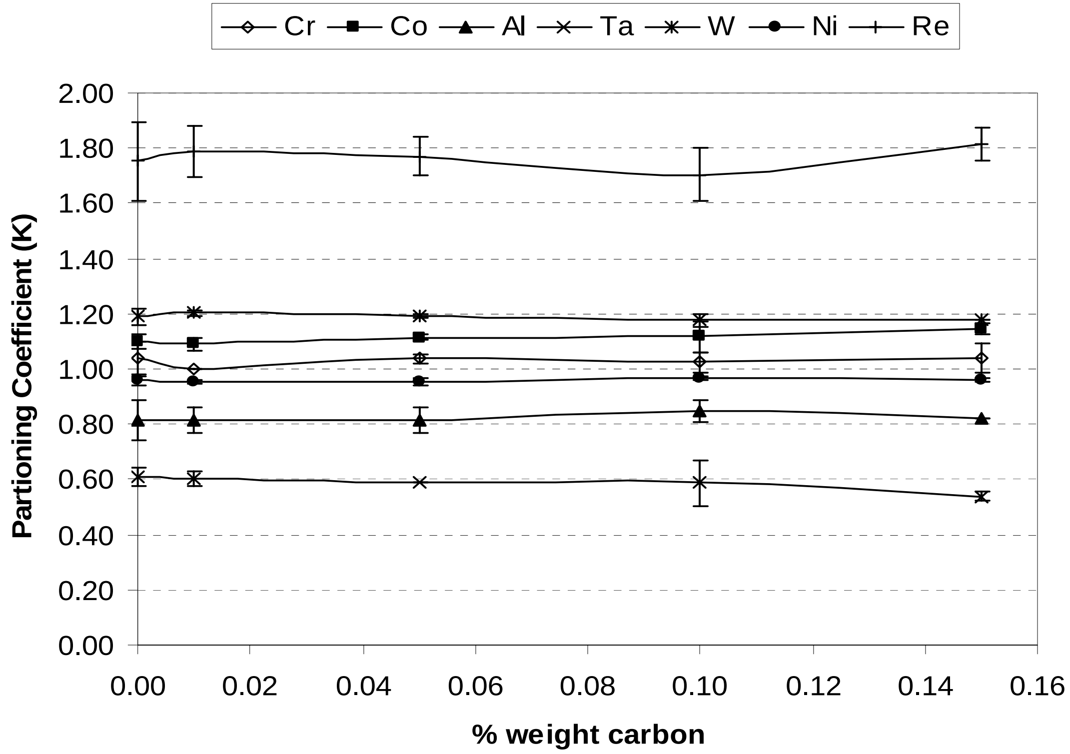
X54

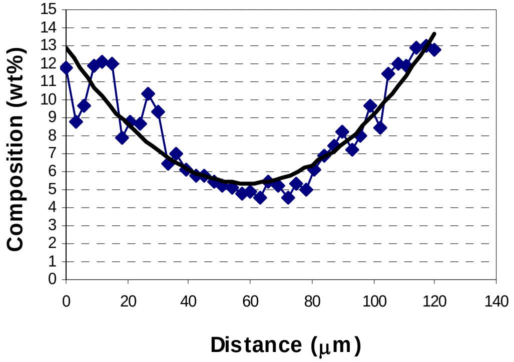


X300

Segregation

- Partitioning coefficient using line scan.
  - Carbon appears to have little effect on segregation





Ta Line Scan

CMSX-4 Work

- 4 molds of CMSX-4 processed at PCC Airfoils
  - Baseline CMSX-4
  - CMSX-4 + C
  - CMSX-4 + C + B
  - CMSX-4 + C + N
- Sample received and preliminary characterization has just been completed
  - Defects:
    - » C additions decrease number of defects
    - » Nand B additions, increase number of defects
  - Segregation
    - » C addition have no effect
    - » B and N additions appear to alter segregation

Where do we go from here?

- Complete processing of Alloy 1
  - Verify phase transformation temperatures
  - Verify segregation
  - Verify microstructural stability
  - Determine properties
- Complete characterization of CMSX-4 + C + B + N
  - Complete analysis of segregation
  - Verify JMatPro results
  - Evaluate properties