NATIONAL ENERGY TECHNOLOGY LABORATORY

Addressing Materials Processing Issues for Steam Turbines: Cast Versions of Wrought Ni-Based Superalloys

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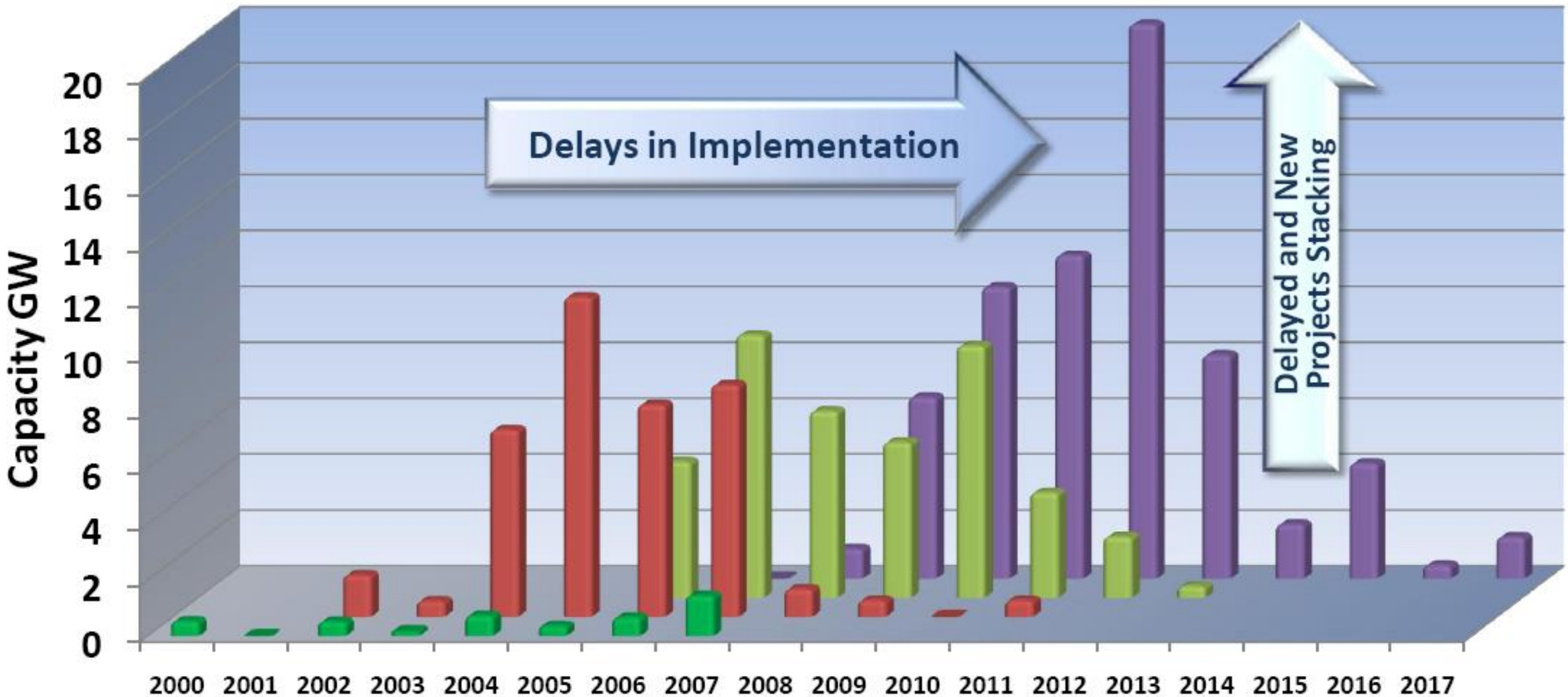
Past Capacity Announcements vs. Actual
Figure 1



Historically, actual capacity has been seen to be significantly less than proposed capacity. For example, the 2002 report listed 36,161 MW of proposed capacity by the year 2007 when actually only 4,478 MW (12%) were constructed.

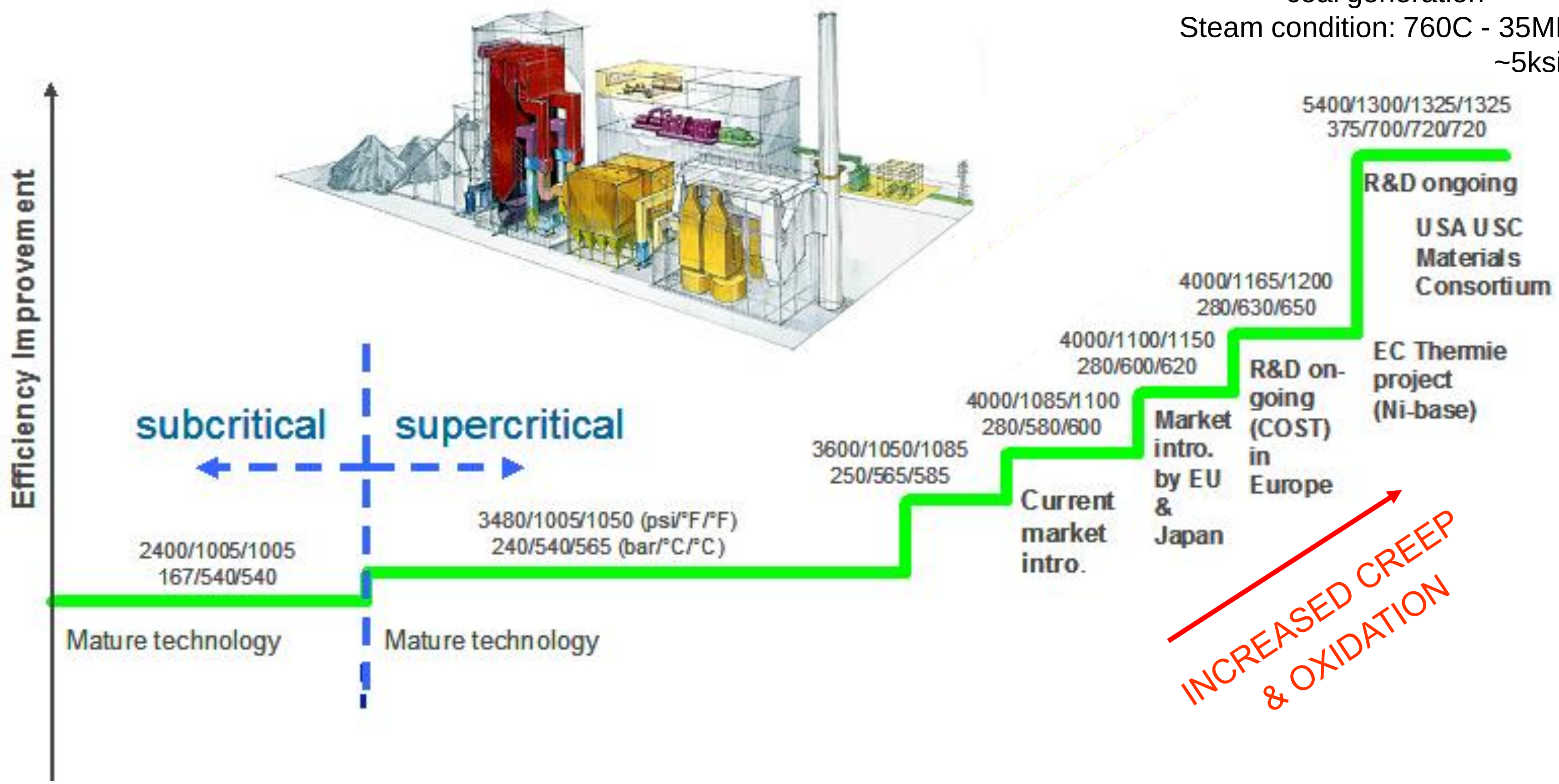
Actual | 2002 Report | 2005 Report | December 2007

NETL

Source: 2007 data Global Energy Decisions – Velocity Suite (12/31/2007)
2002 – 2005 data – Previous NETL Tracking New Coal-Fired Power Plants Reports

Increasing Efficiency: A-USC Plants

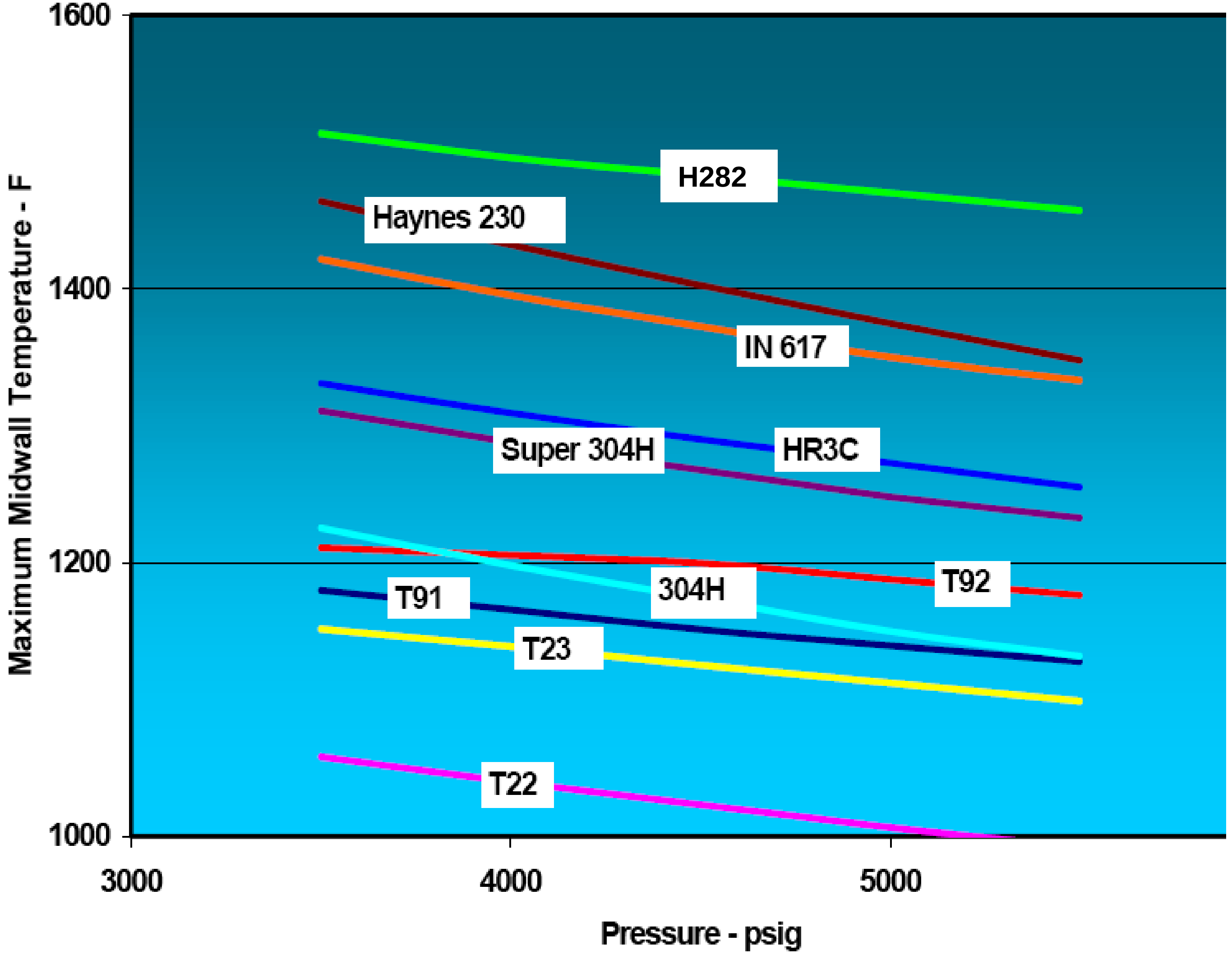
US-DOE Advanced Power System Goal: ~46% efficiency from coal generation
Steam condition: 760C - 35MPa ~5ksi



Plants operation above 22MPa at 538 to 565C are “supercritical”; above 565C are “ultra-supercritical” (USC)

Source: Viswanathan, et al 2005

Maximum Use Temperature



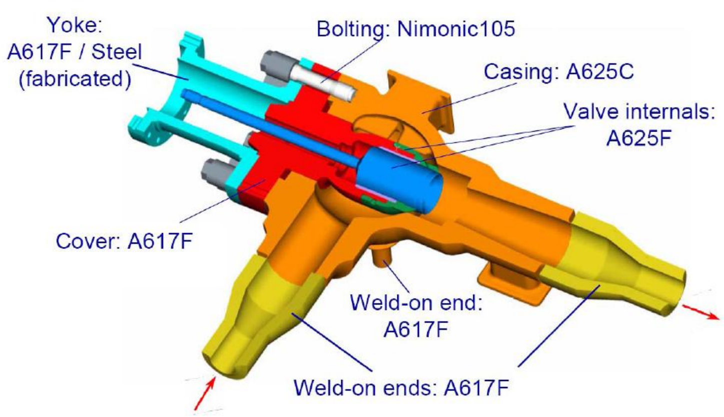
Source: Viswanathan, et al 2005

Technological Issues

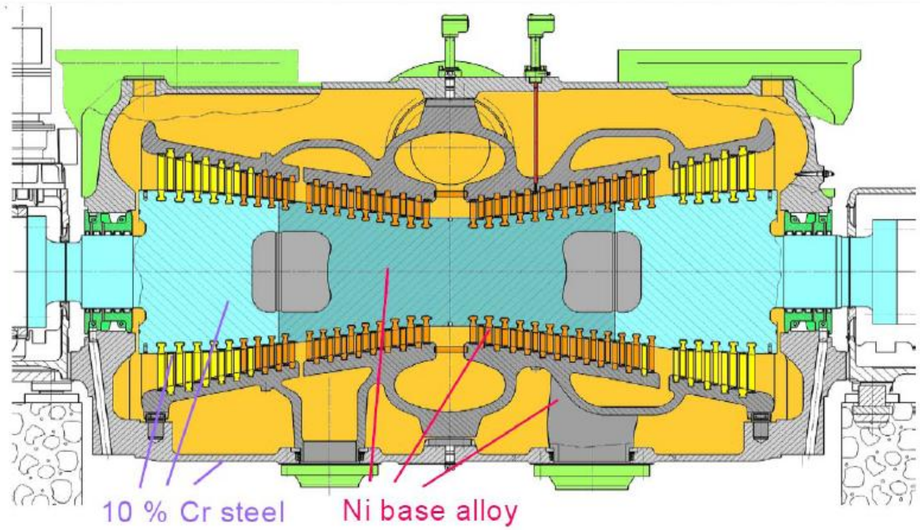
- **There is an immediate and continuing need for increased power production.**
- **Portfolio diversification dictates the use of coal.**
- **Increases in Temperature and Pressure increase efficiency and decrease CO_2 production along with other pollutants.**
- **Higher Temperature and Pressure place greater demands upon the Materials.**
- **Large castings are required for some components—many technical issues.**

Example Components

- **Castings**
  - 1-15 tons
  - Up to 100mm in thickness



Valve Bodies



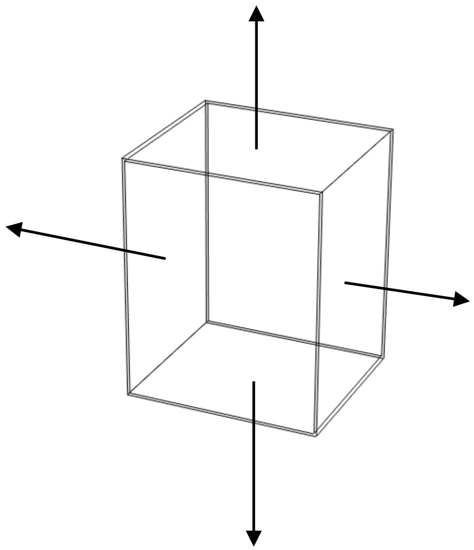
Turbine Casing

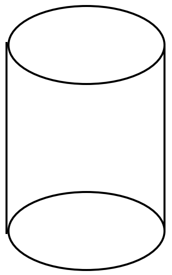
Courtesy Alstom

Alloys Under Consideration

Solid Solution	Age Hardenable
H230	N105
IN617	N263
IN625	H282
	IN740

Our Model Casting Geometry

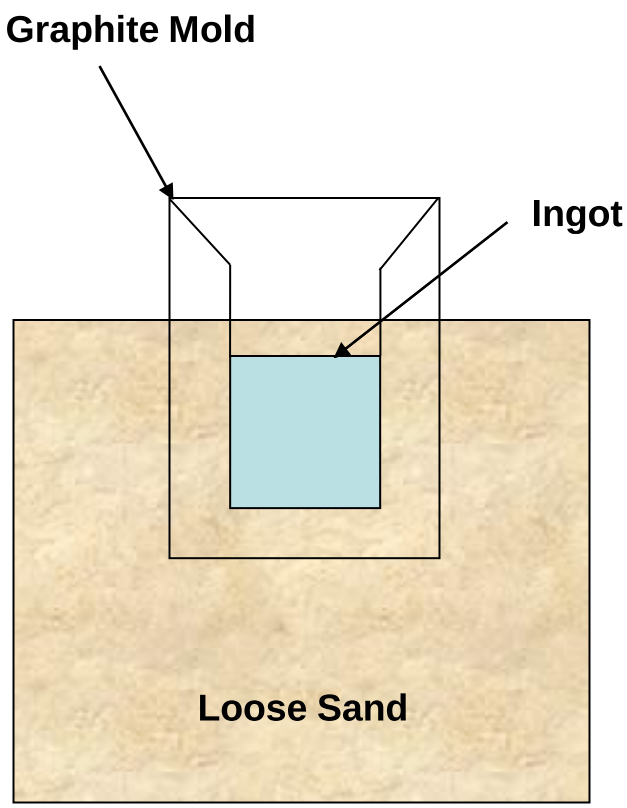




The actual component is nominally 4in thick and "infinite" in the other directions.

Our casting is nominally 4in in diameter and 4-5in tall.

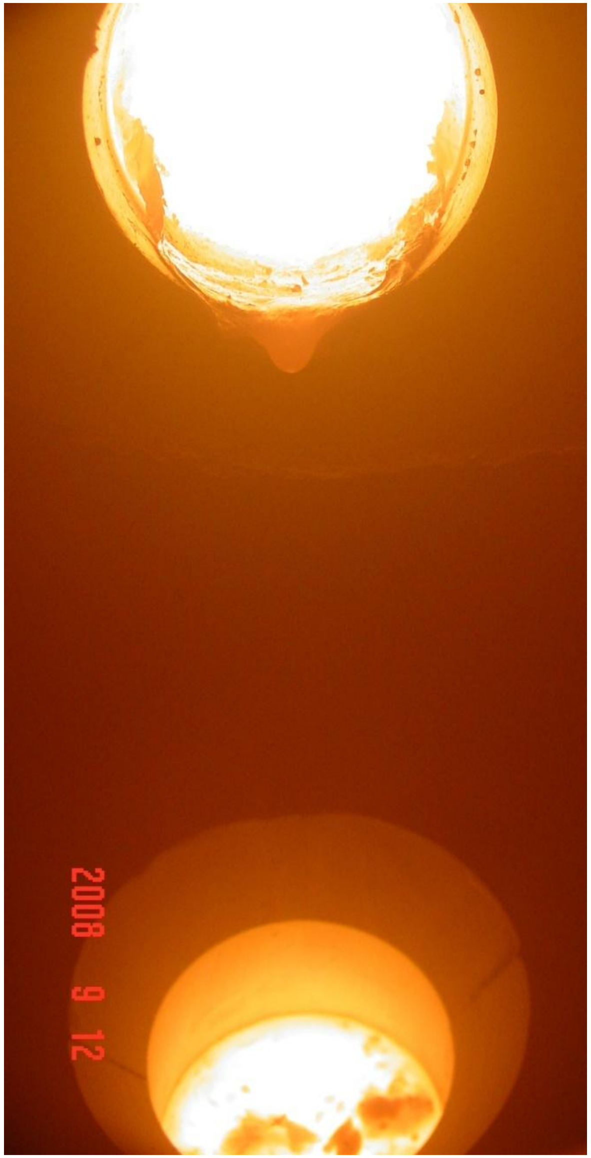
“Enhanced” Slow Cooling



Our casting layout is shown schematically in cross section on the left. A permanent graphite mold was used. This mold was surrounded by loose sand such that the top of the casting was below the sand line. This is our attempt to emulate the “semi-infinite” plate model of the turbine casing.

Model Casting Results

Empty melt crucible.

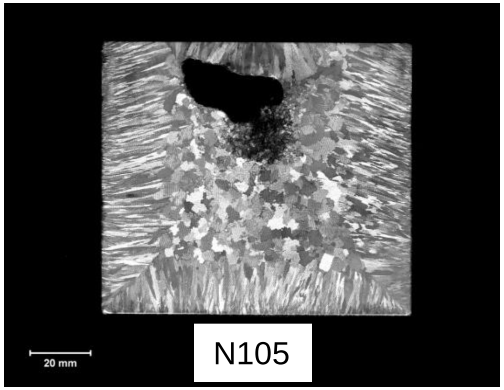


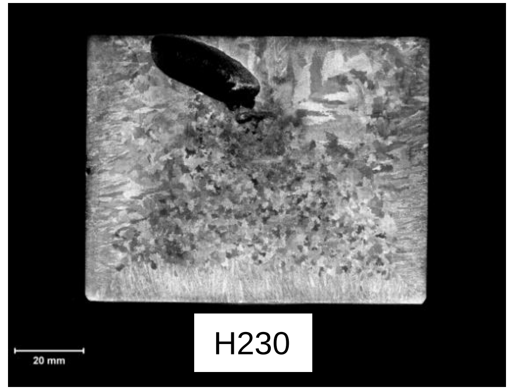
Full mold

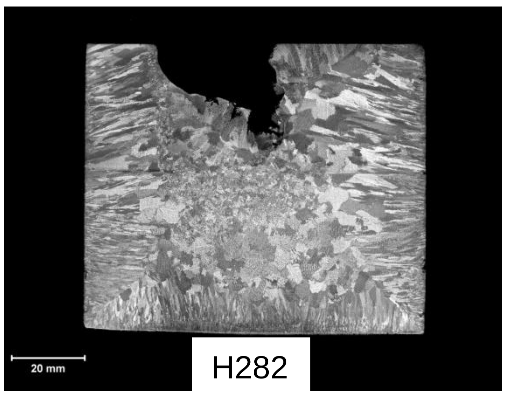
(Ingot top is below loose sand line).

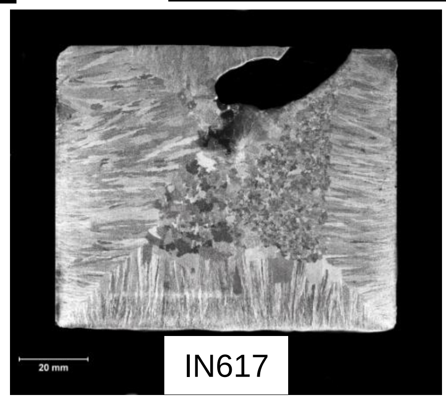
Photo taken moments after casting. The mold never showed any "color" which meant that the mold temperature stayed below about 550C. This gave us some confidence that slow cooling was achieved.

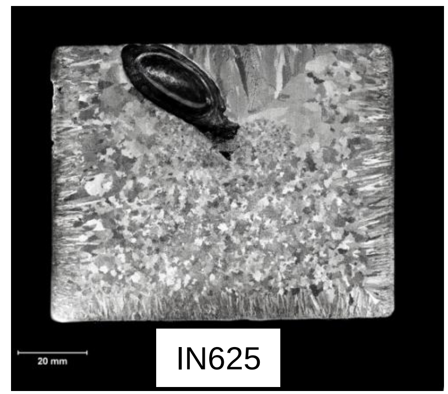
Grain Etched Ingot Cross Sections

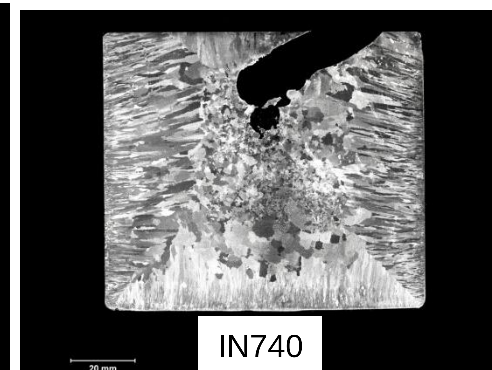












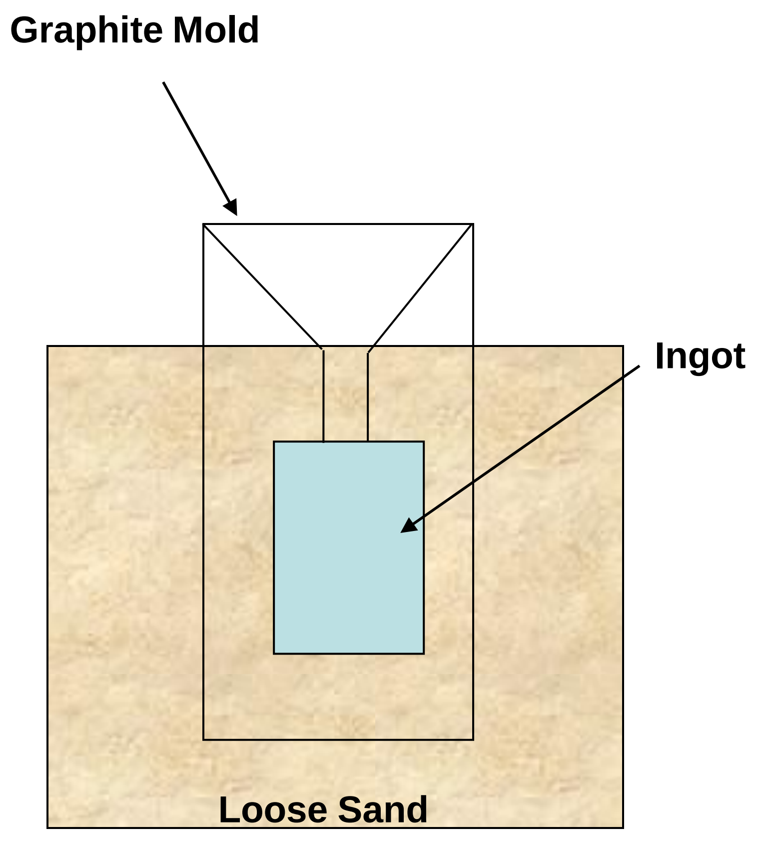
Ingots were sectioned to bisect the shrink cavity.

In general, the ingots have a columnar outer band ~1/4-1/3 of the radius thick and an equiaxed core. This is similar to the grain structure we would expect to observe in a large sand cast version of these alloys.

First Ingot Chemistries

	C	Cr	Mo	Co	Al	Ti	Cb	Mn	Si	B	W	
Nimonic 105	0.15	14.85	5.00	20.00	4.70	1.10		0.50	0.50	0.05		**Aims**
	0.16	*14.61*	*5.02*	*20.04*	*4.43*	*1.10*		*0.51*	*0.51*	*0.05*		***Results***
Haynes 282	0.070	19.50	8.50	10.00	1.50	2.10		0.25	0.15	0.005		
	0.07	*19.22*	*8.48*	*9.84*	*1.44*	*2.08*		*0.24*	*0.15*	*0.01*		
IN740	0.030	25.00	0.50	20.00	1.30	1.50	1.50	0.30	0.30	Fe:	0.70	
	0.04	*24.71*	*0.50*	*20.03*	*1.24*	*1.48*	*1.50*	*0.30*	*0.31*		*0.57*	
Nimonic 263	0.070	20.00	5.80	20.00	0.35	2.10		0.50	0.35			
	0.07	*19.68*	*5.74*	*19.89*	*0.40*	*2.04*		*0.50*	*0.34*			
Haynes 230	0.120	22.00	2.00		0.35			0.70	0.50		14.00	
	0.12	*21.59*	*2.01*		*0.37*			*0.69*	*0.50*		*13.91*	
IN617	0.120	22.00	9.00	12.50	1.10	0.30		0.50	0.50			
	0.12	*21.73*	*8.96*	*12.35*	*1.04*	*0.31*		*0.50*	*0.49*			
IN625	0.070	21.00	9.00		0.10	0.10	3.60	0.50	0.35			
	0.07	*20.71*	*8.92*		*0.15*	*0.089*	*3.58*	*0.49*	*0.34*			

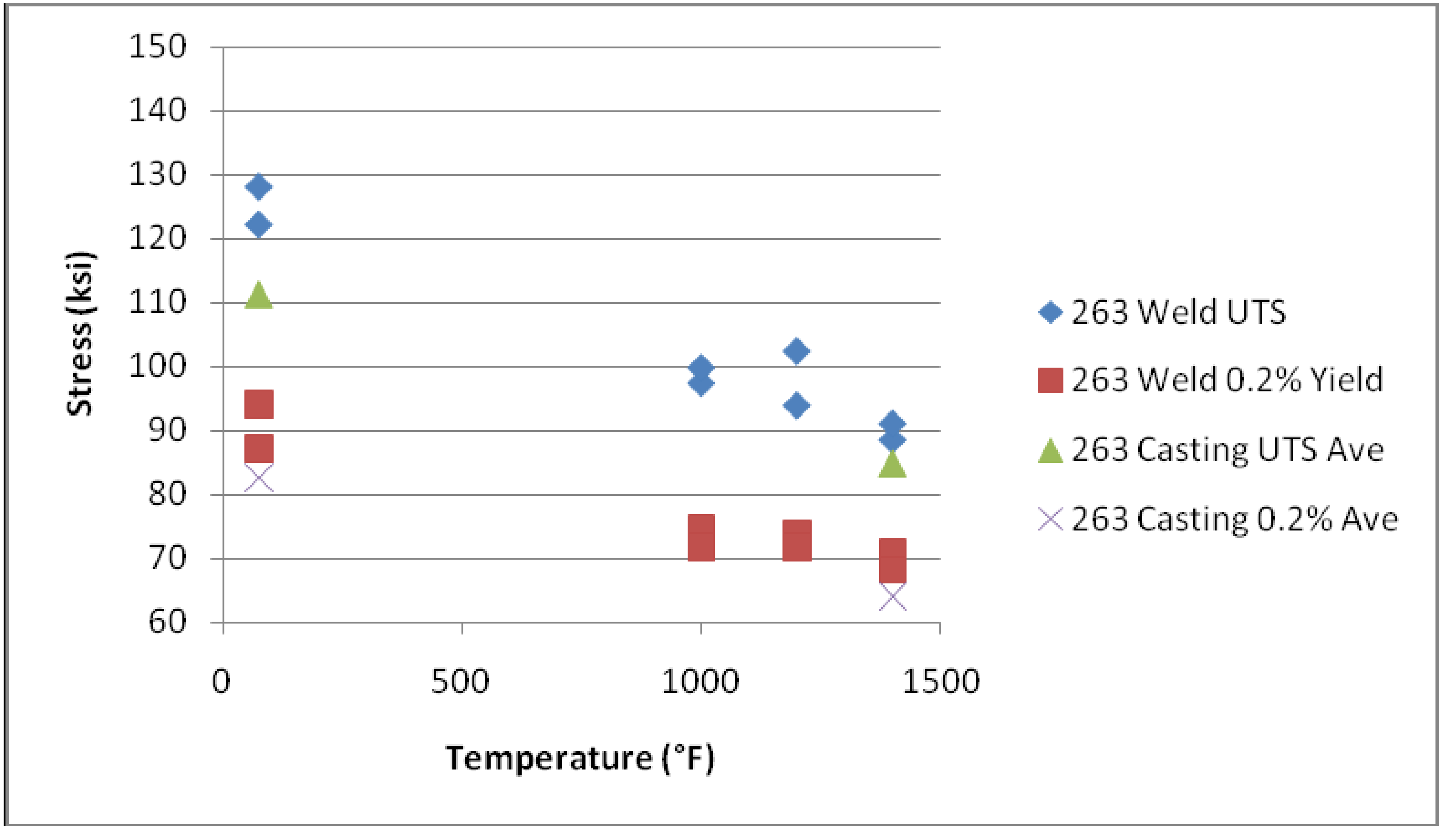
Casting the Plate For Welding Studies



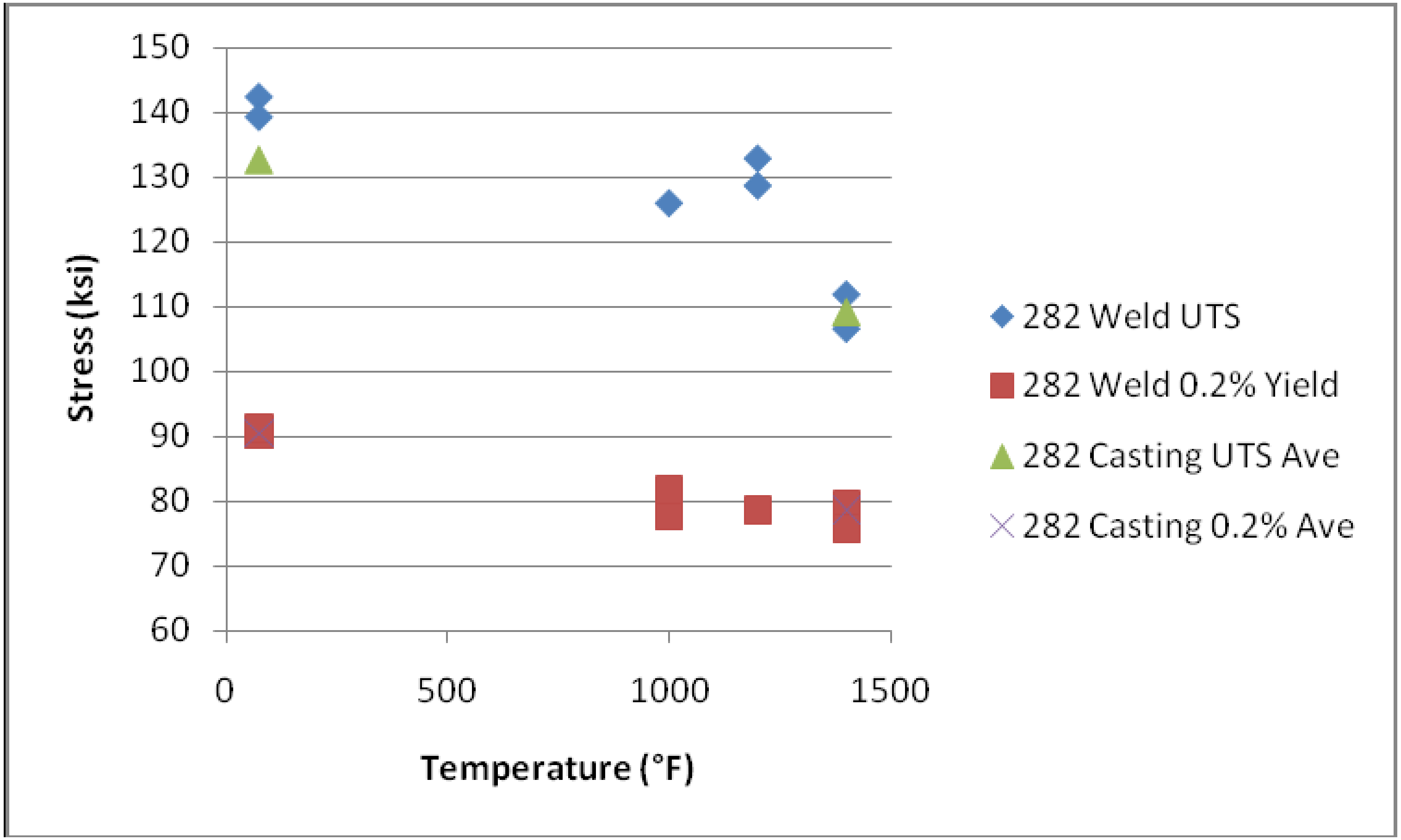
Our casting layout is shown schematically in cross section on the left. A permanent graphite mold was used. This mold was surrounded by loose sand such that the top of the casting was covered with sand. This is our attempt to emulate the "semi-infinite" plate model of the turbine casing.

Welded Plates

263 Cross Welds



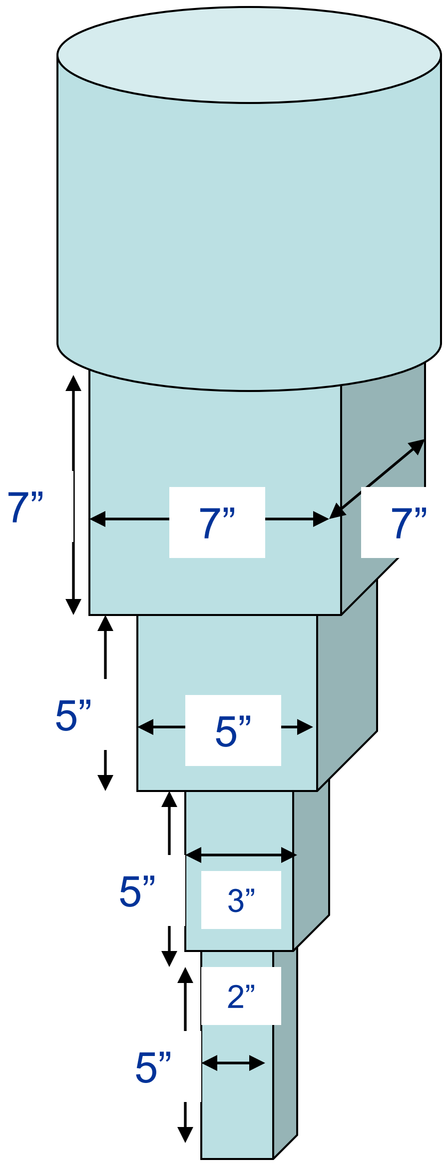
H282 Cross Welds



Project Tasks

- **Cast plates from selected alloys for weldability:**
  - *Casting complete*
  - Evaluation underway
- **Work with GE to develop a feature laden prototype casting to be cast at an outside vendor**
  - Castings are too large for traditional investment casting vendors
  - Majority of sand casting vendors cast iron and steel
  - First vendor identified bowed out
  - Second vendor identified and article cast and homogenized
  - Third vendor identified and article cast and homogenized

Casting Geometry



8" x 8" Volume: 402 in^3

Blend radius 1"

7" x 7" x 7" Volume: 343 in^3

Blend radius 1"

5" x 5"x 5" Volume: 125 in^3

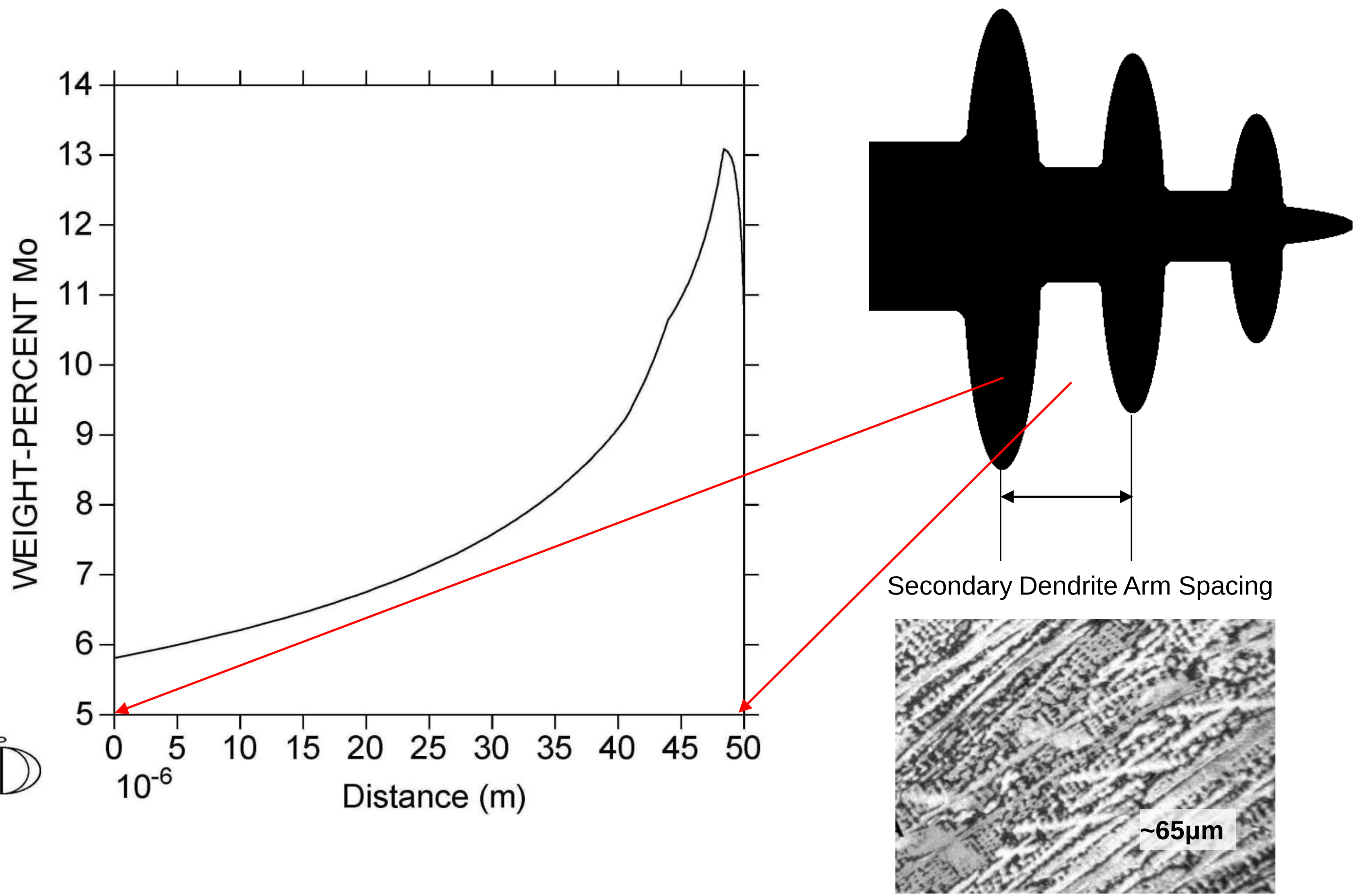
Blend radius 1"

3" x 5" x 5" Volume: 125 in^3

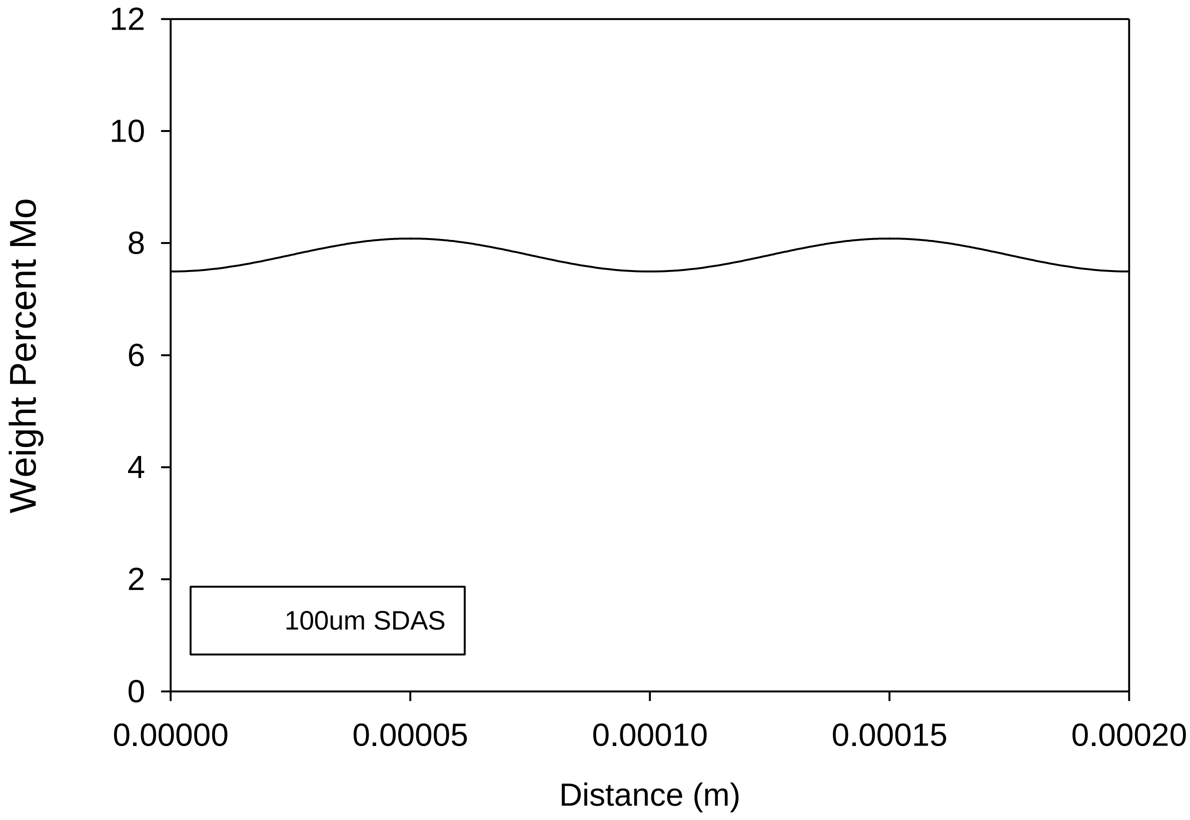
Blend radius 0.75"

2" x 5" x 5" Volume: 125 in^3

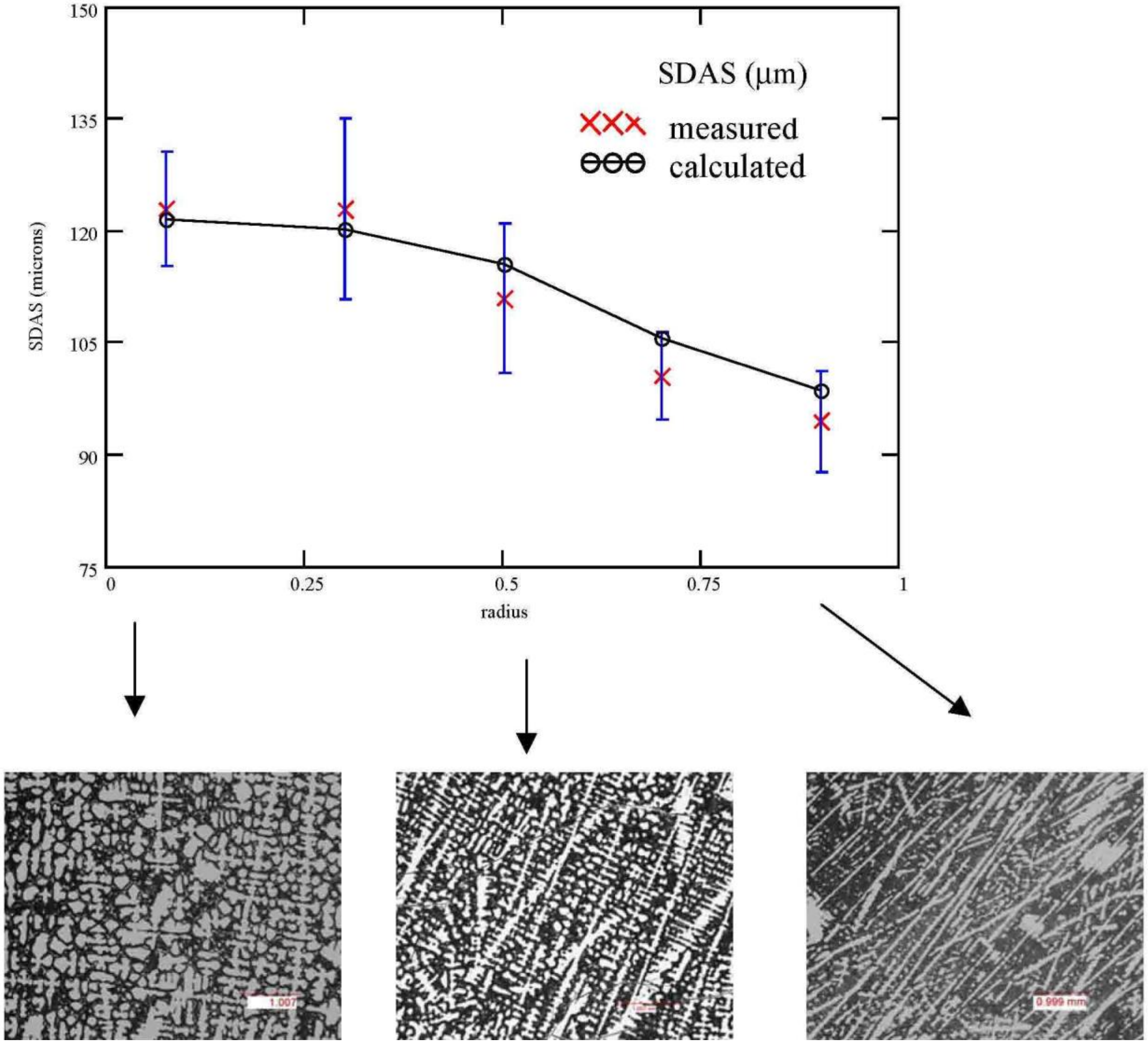
Segregation Within the FCC Phase



Remnant Segregation After Homogenization

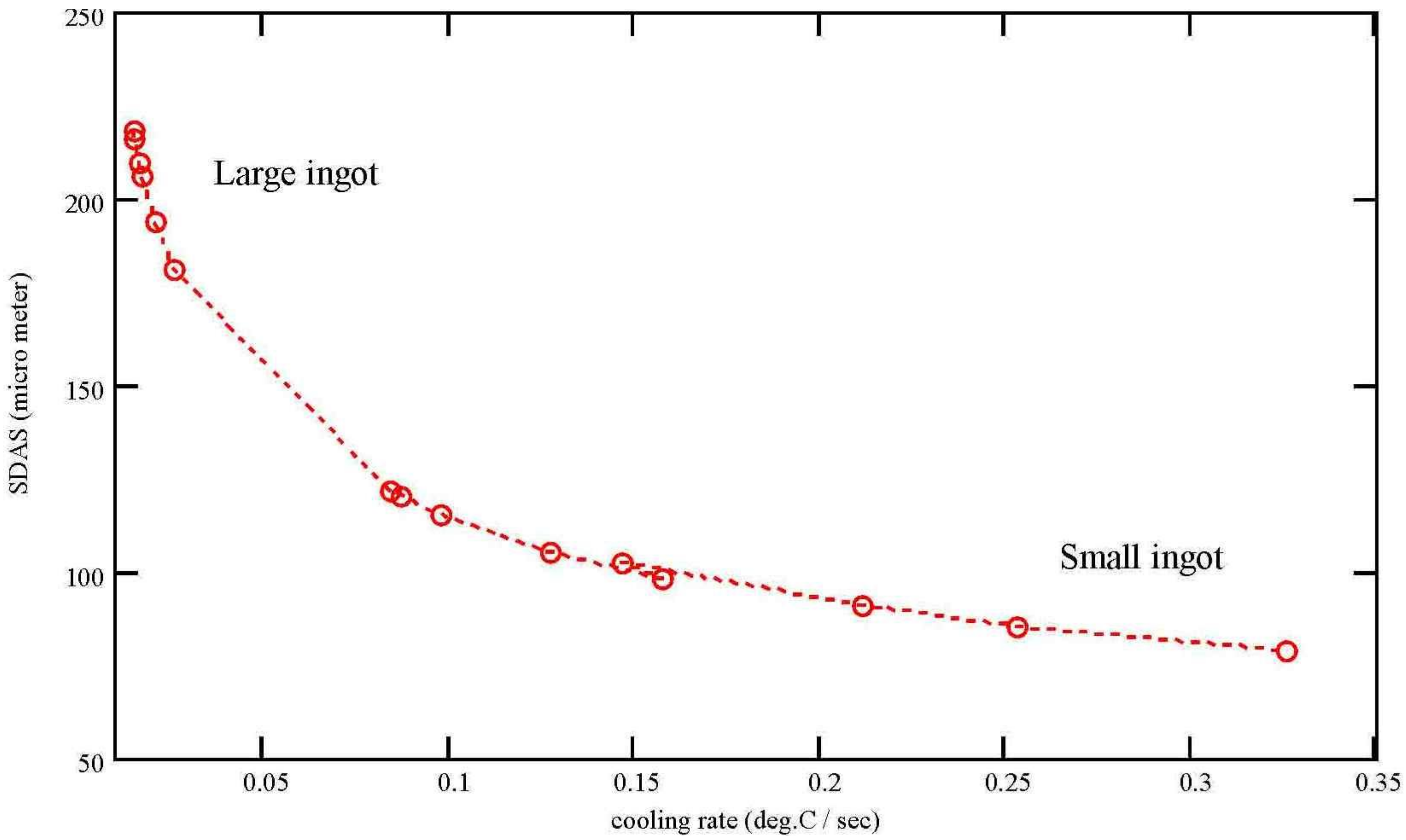


SDAS—Effect of Position



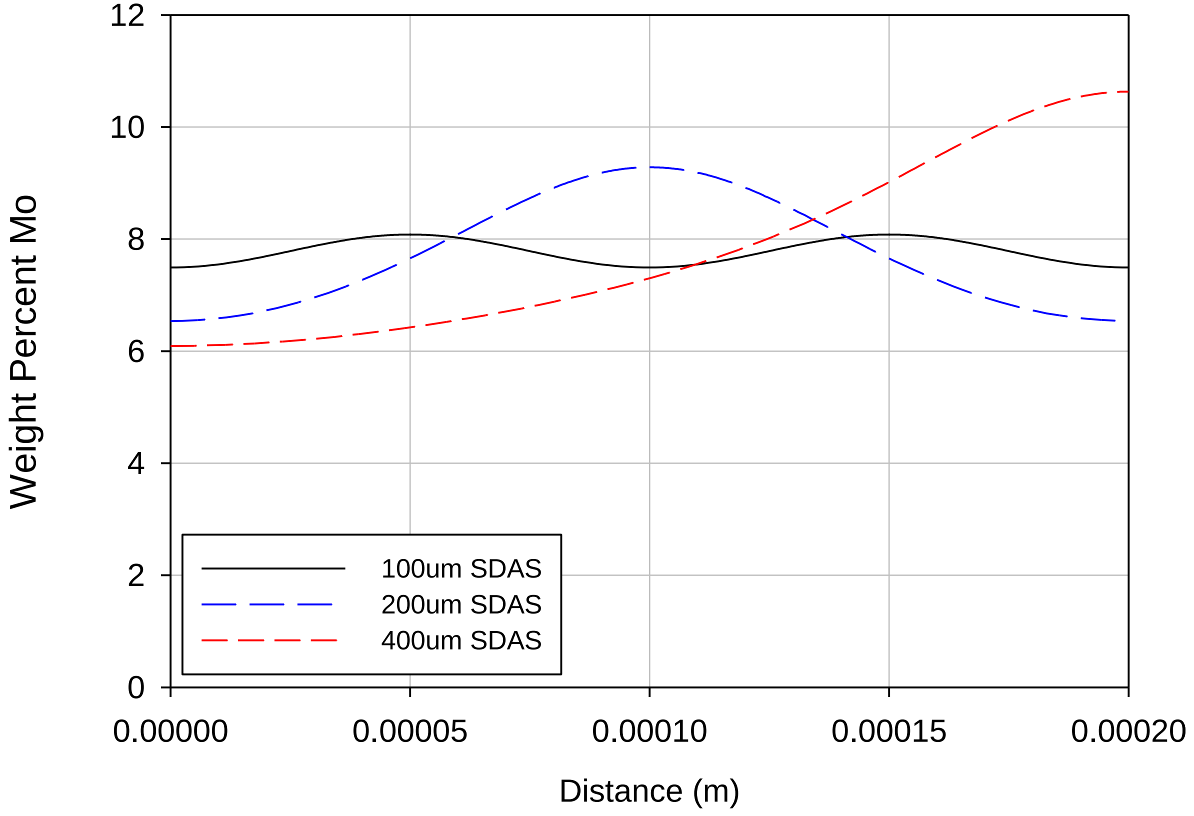
Patel and Murty, 718 conf. (2000)

SDAS—Effect of Cooling Rate

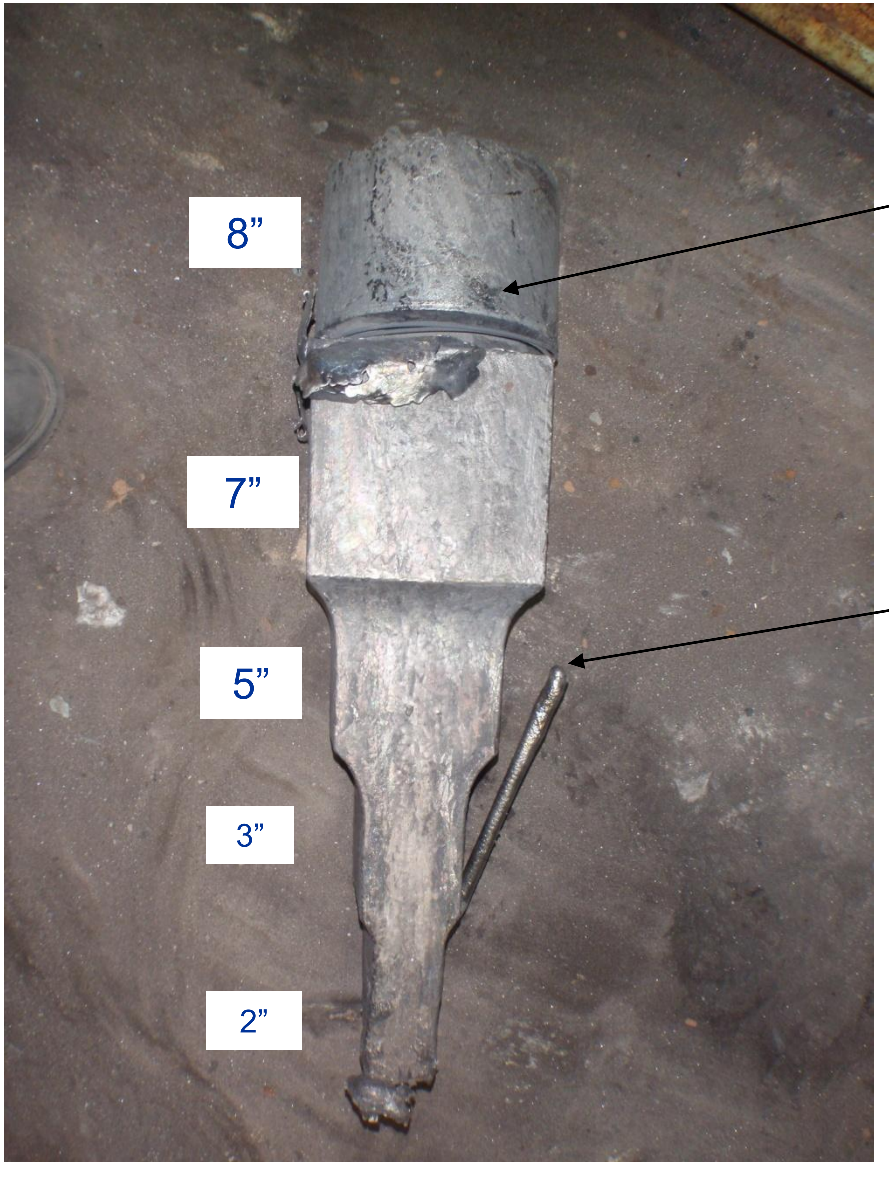


Patel and Murty, 718 conf. (2000)

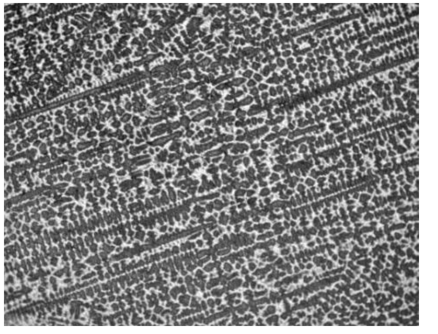
Effect of SDAS on Homogenization



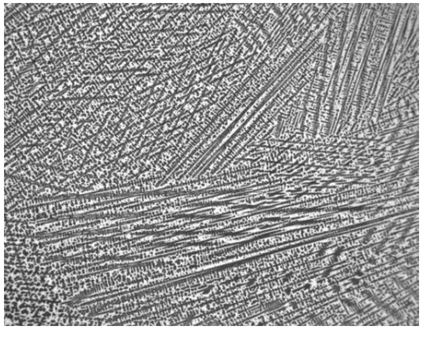
SDAS in Larger Casting



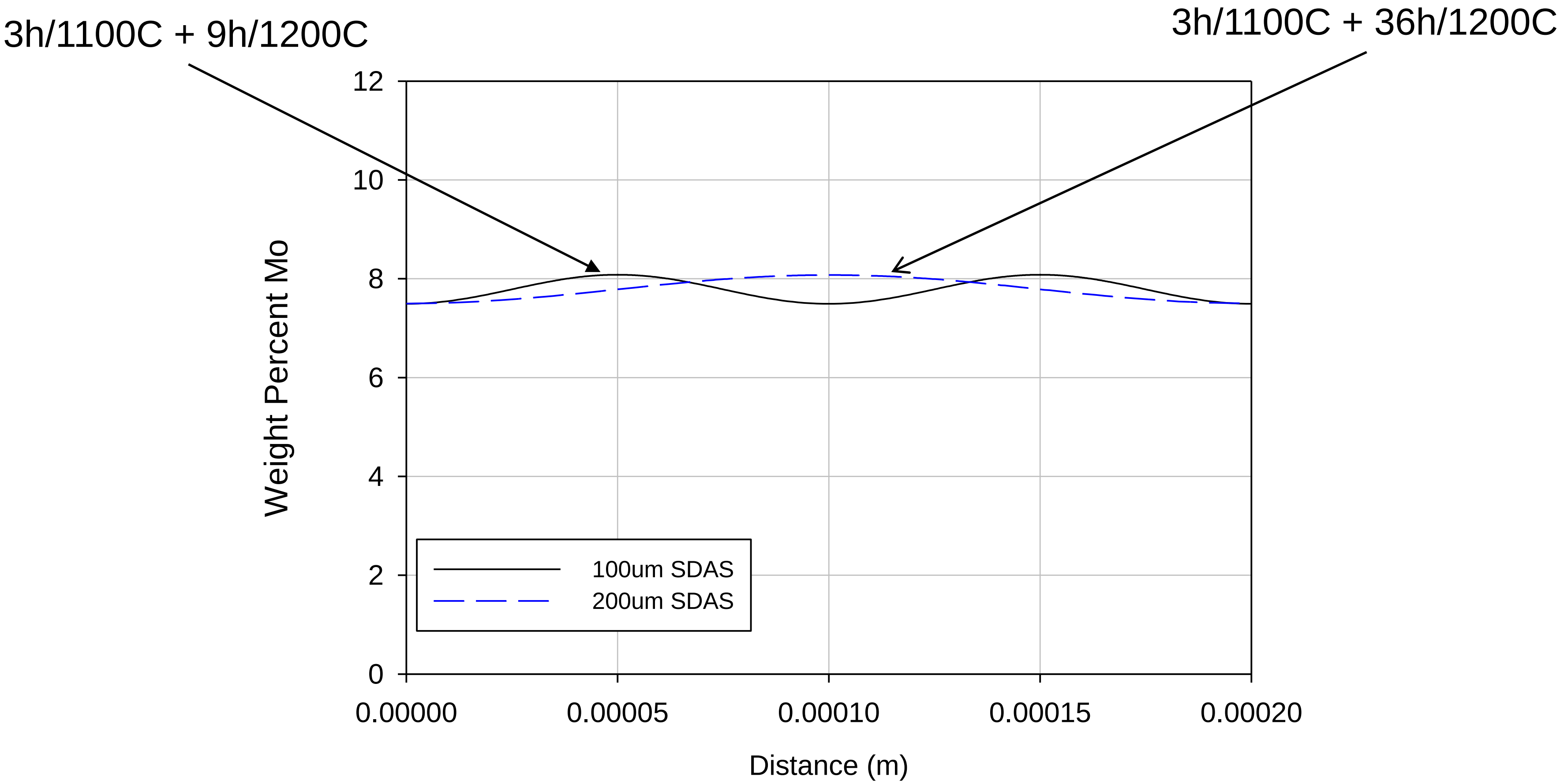
Riser Pad SDAS: 154-188µm



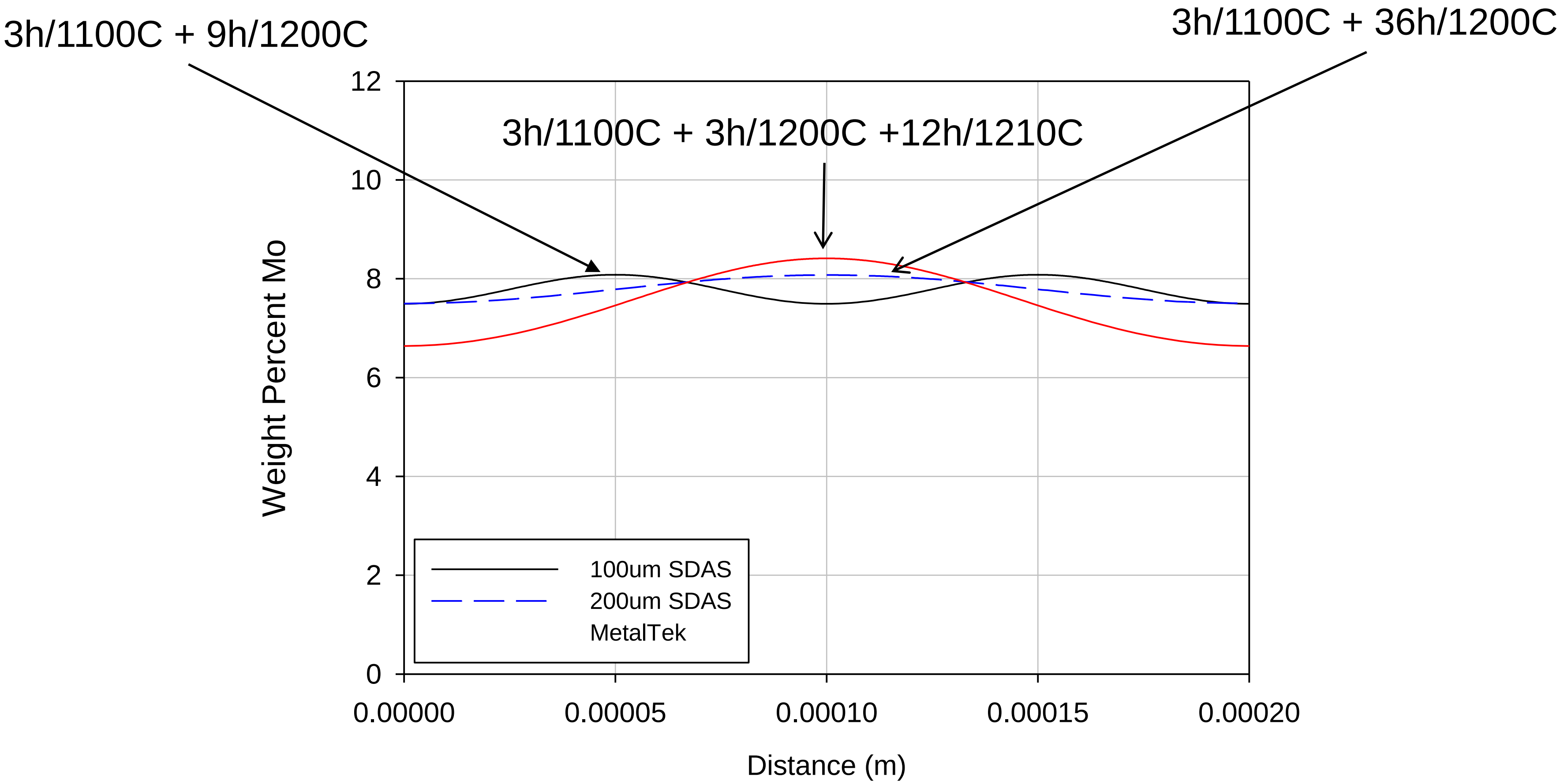
Keel Block SDAS: 67-57µm



Adjusting of Scale of Microstructure



Application to the Casting

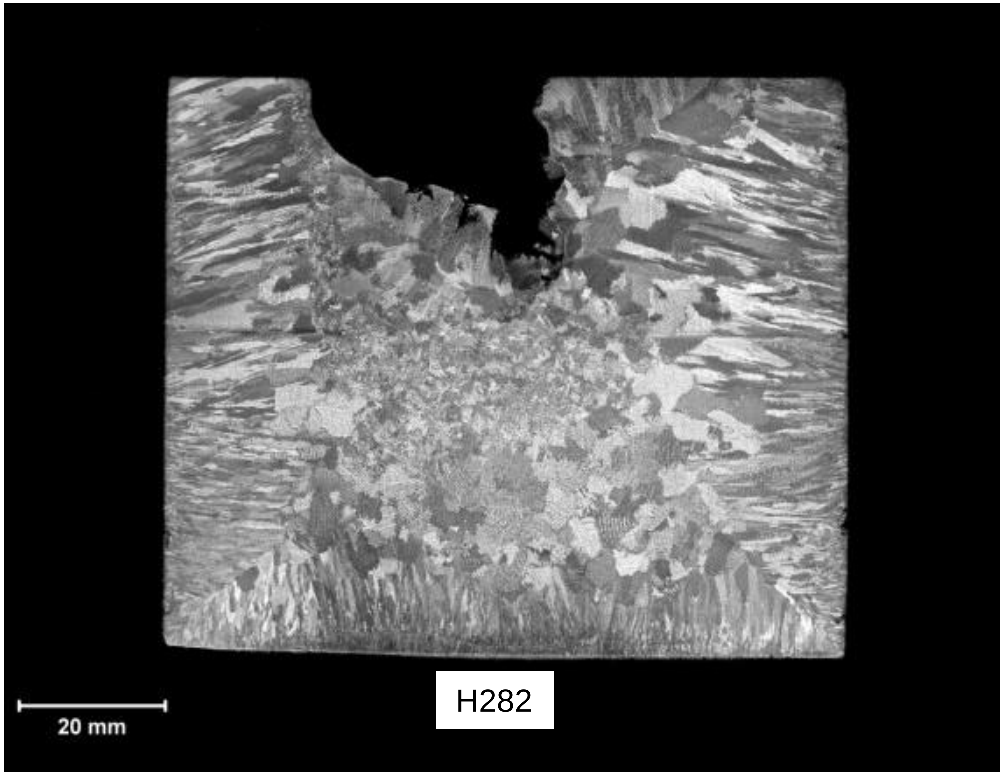


Residual Mo Segregation

		Minimum (%)	Maximum (%)
As-Cast	Predicted		
	Measured	89	127
Long time HT	Predicted	94	106
	Measured	94	101
HT Applied	Predicted	91	109
	Measured	92	111

Superheat

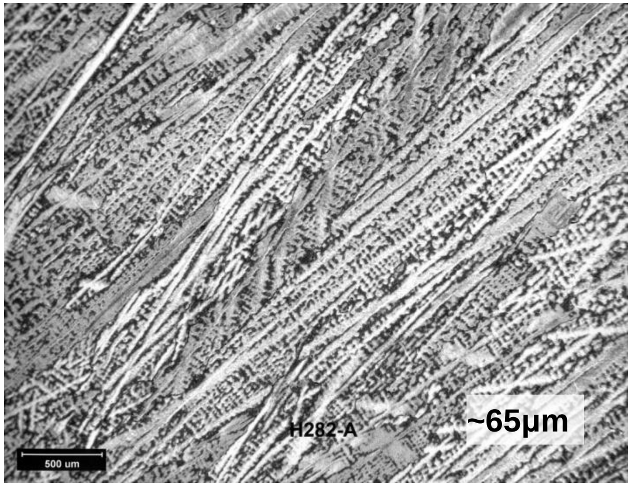
Grain Etched Ingot Cross Section



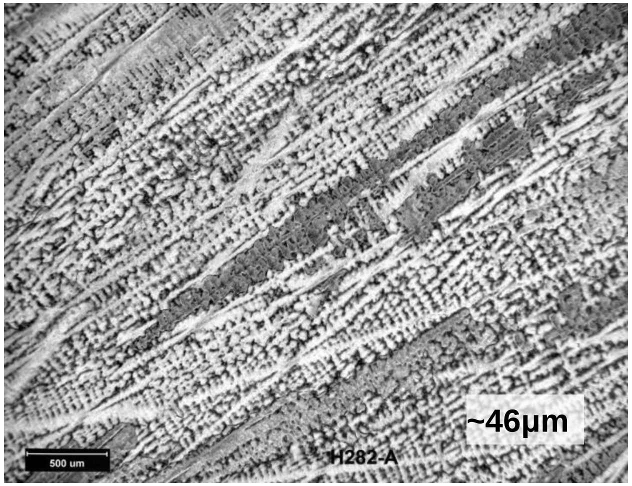
Ingots were sectioned to bisect the shrink cavity.

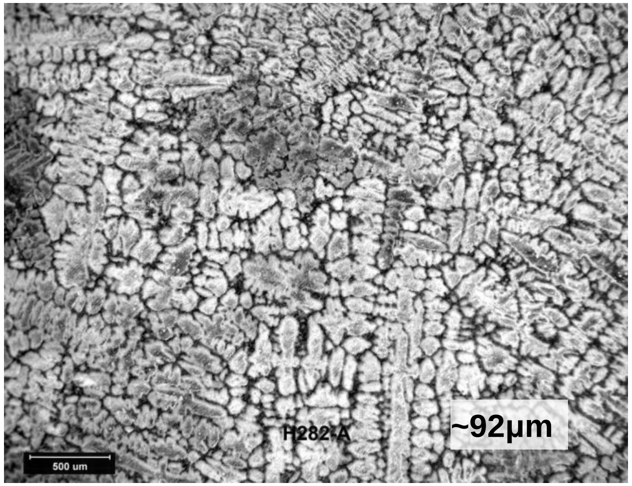
In general, the ingots have a columnar outer band ~1/4-1/3 of the radius thick and an equiaxed core. This is similar to the grain structure we would expect to observe in a large sand cast version of these alloys.

H282 Secondary Dendrite Arm Spacing

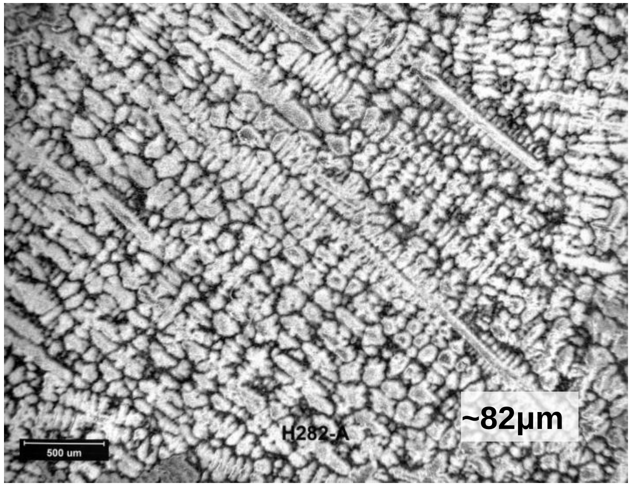


Columnar zone

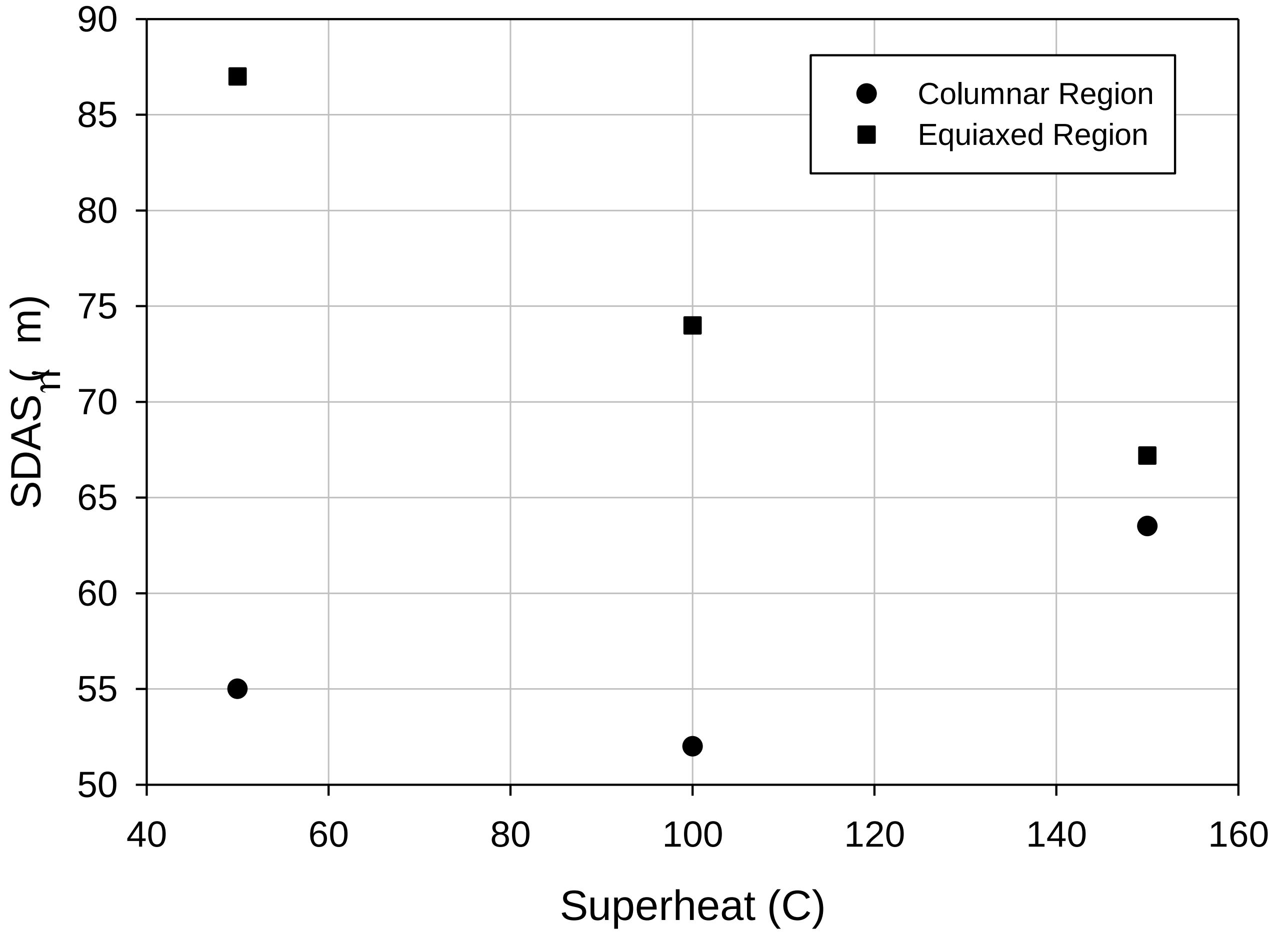




Equiaxed zone

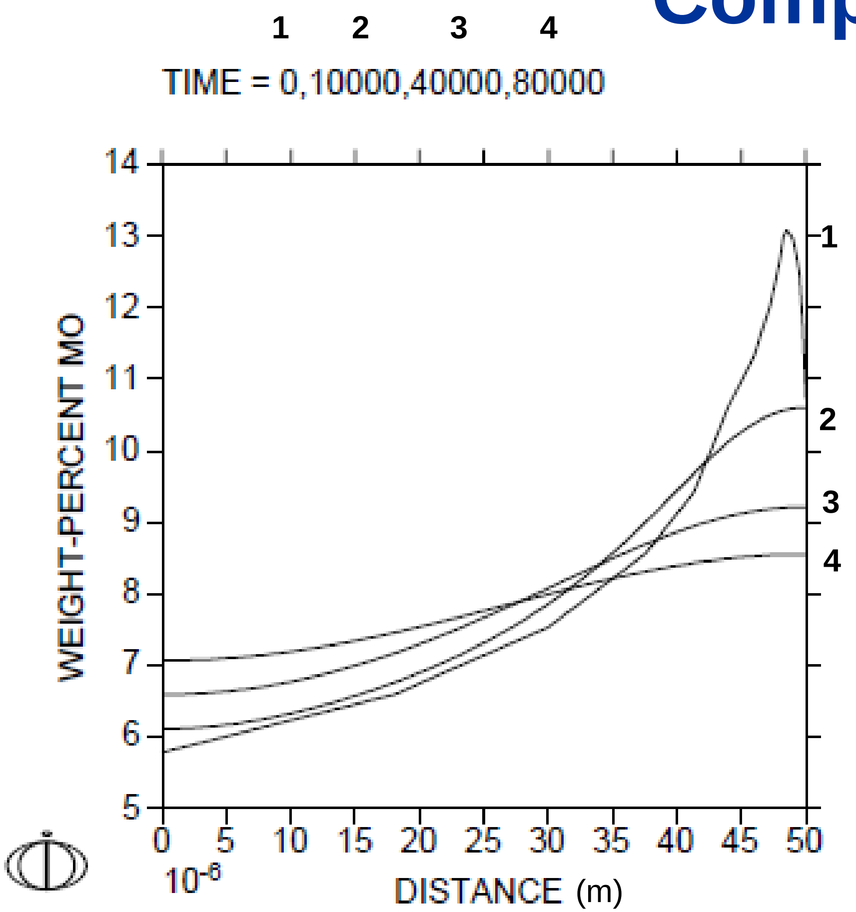


Superheat

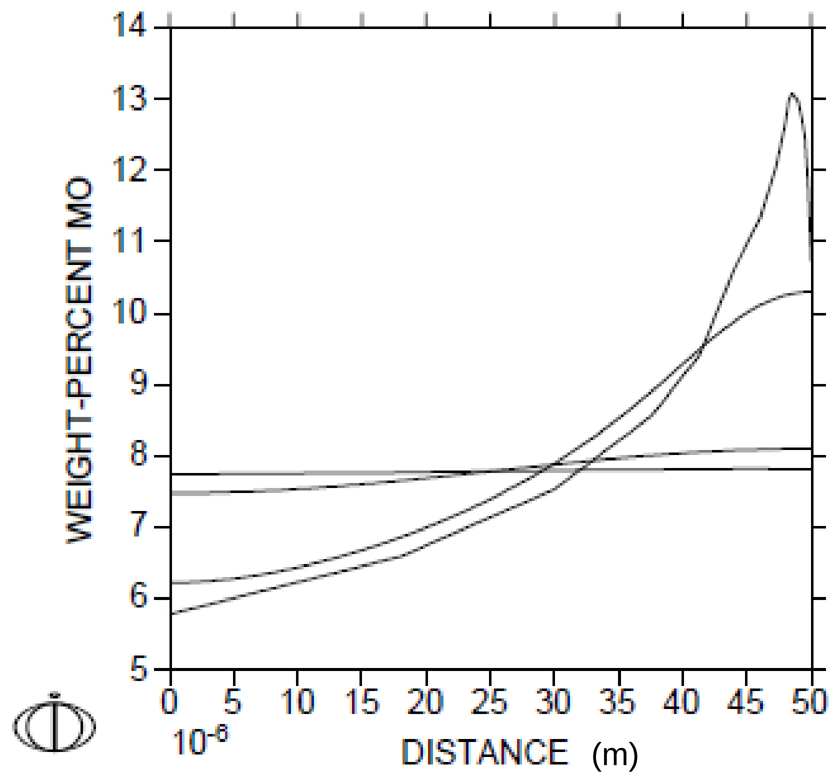


90
85
80
75
70
65
60
55
50
40
60
80
100
120
140
160
SDAS (μm)
Superheat (C)
Columnar Region
Equiaxed Region

H282—Homogenization Heat Treatment Comparison



Isothermal at 1100C

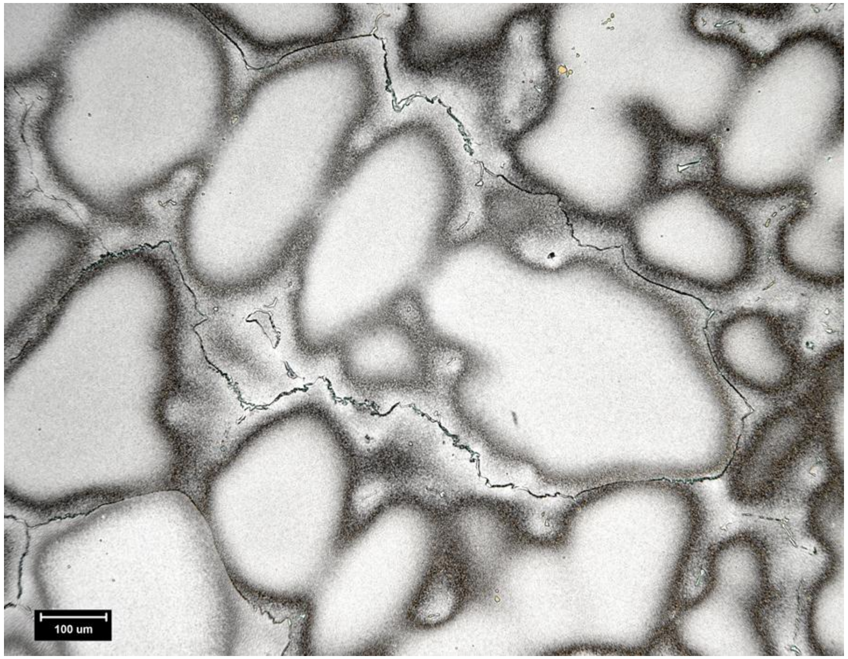


1100C/10,000s+1200C/remaining time

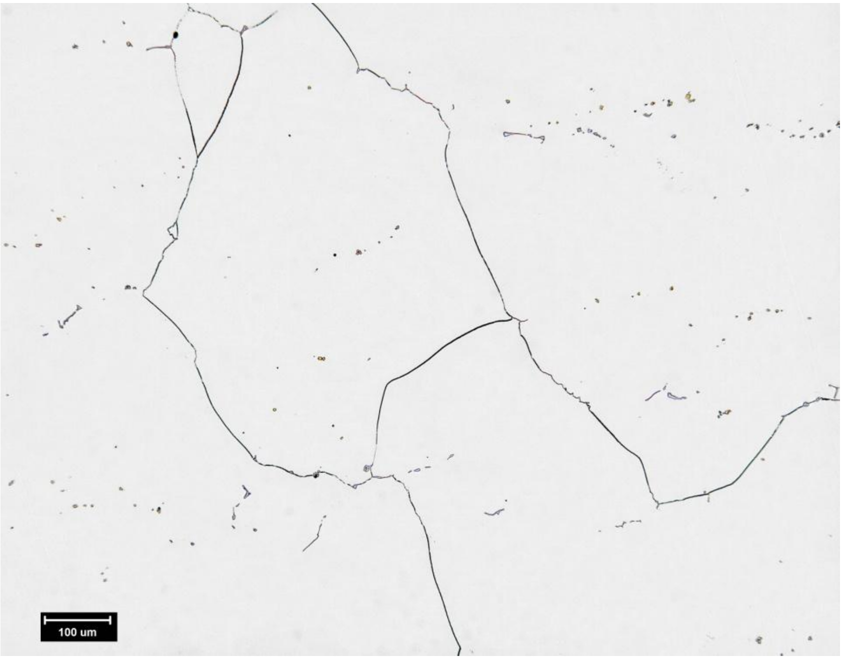
Patent Pending
*Metall. Trans. B, **40B**, (2009) 182.*

As-Cast vs. Homogenized H282

Qualitative Confirmation of the Effectiveness of the Homogenization Heat Treatment

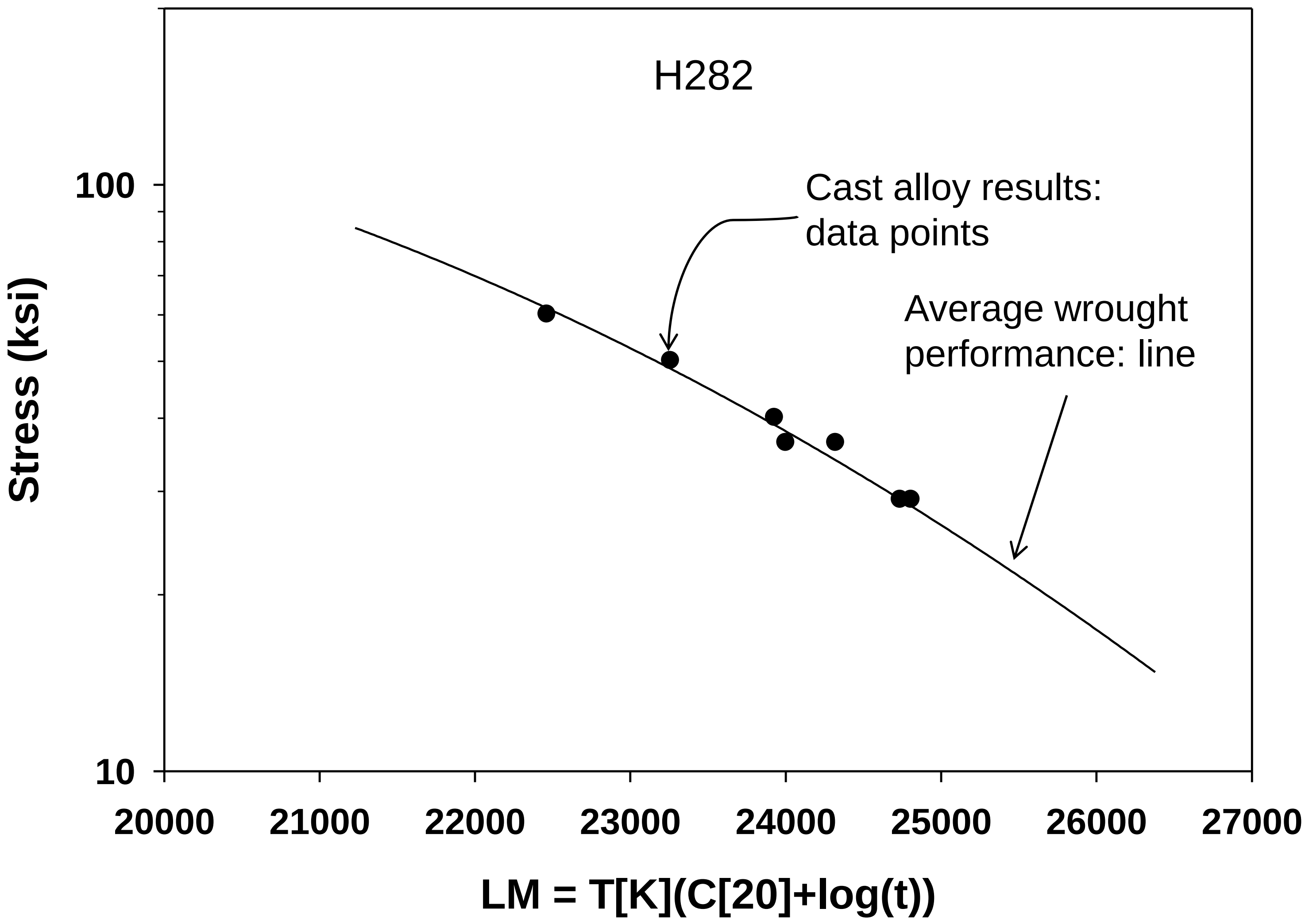


As-Cast



Homogenized

800C Creep Results

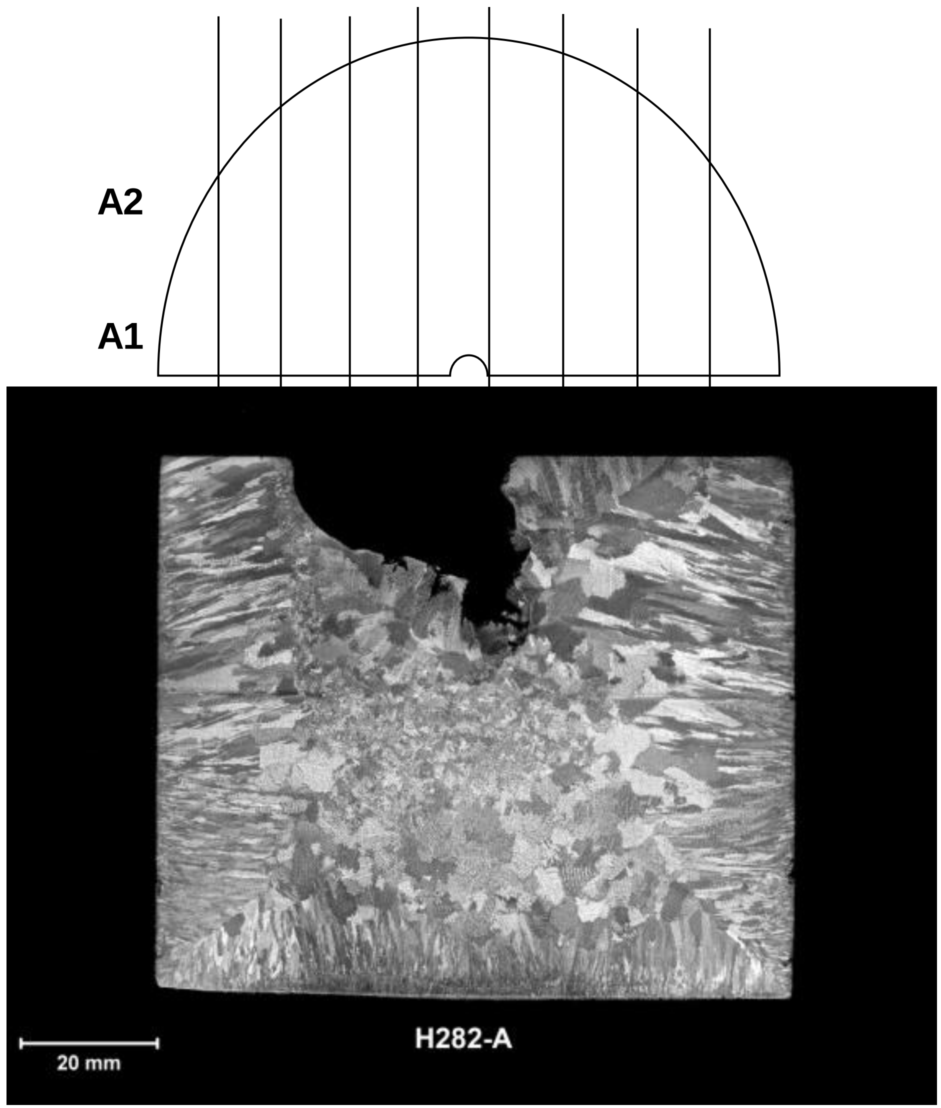


Section Summary: As-Cast Profiles

- **The refractory elements W, Mo, and Nb do not homogenize after ~22h/1100C**
- **Significant segregation of the second phase strengthening elements Al, Ti and Nb were observed in many alloys…to the point that 1/2-2/3 of the casting would be considered "lean".**
- **In some cases, Cr poor regions are predicted.**
- **Significant Co segregation was observed in some alloys.**
- **Significant partitioning of Mn and Si to the interdendritic region was predicted. This result suggests that a turn down in the levels of these elements may be beneficial (e.g., welding).**

Tensile Bar Layout

The ingot halves were cut into 0.4in wide slabs labeled A, B, etc. from the left side of the original tops. These were cut into 0.4in wide TB blanks labeled A1, A2, etc. from the ingot center.



Alloy 263 Fracture

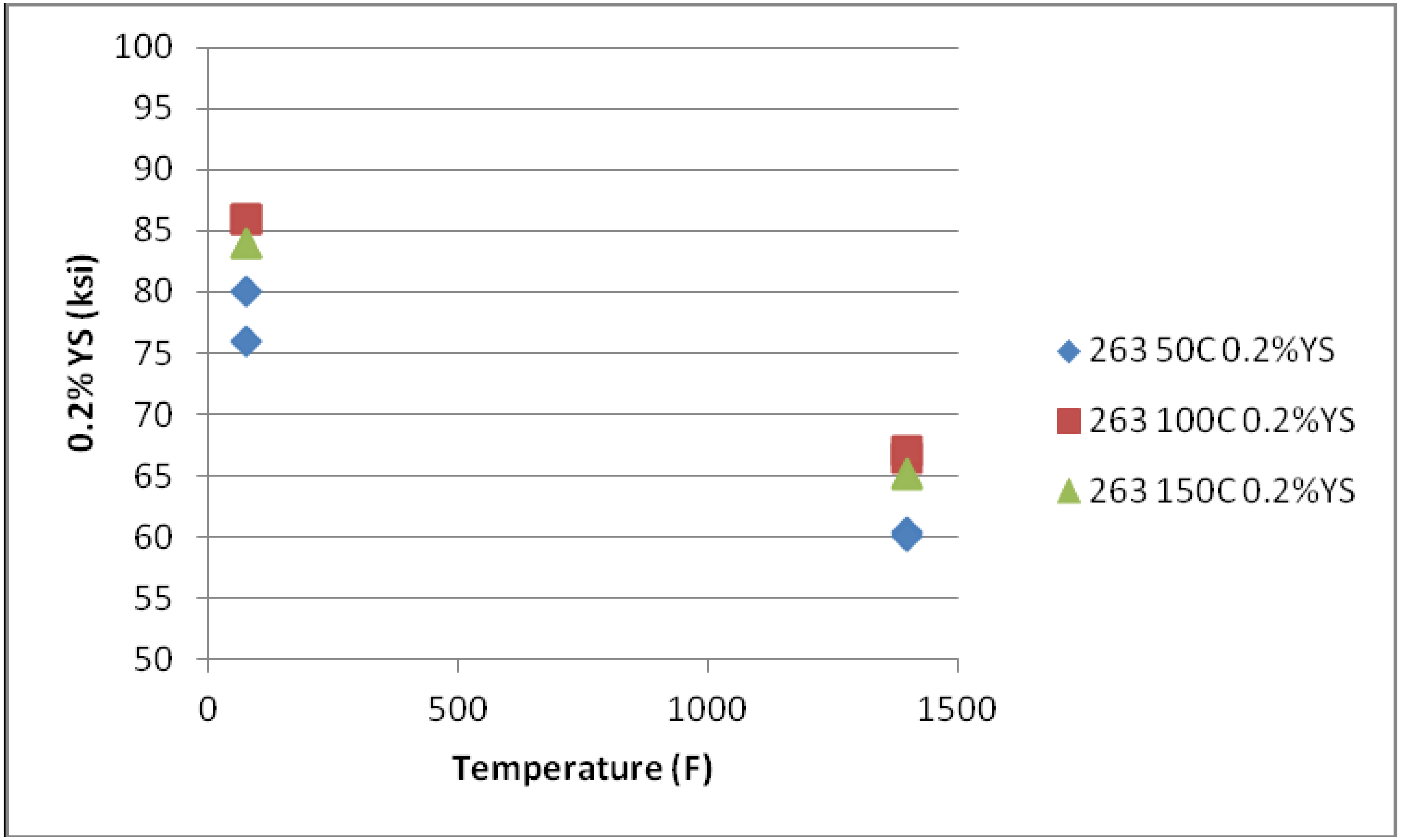
800C Hot Tensile

Equiaxed Region

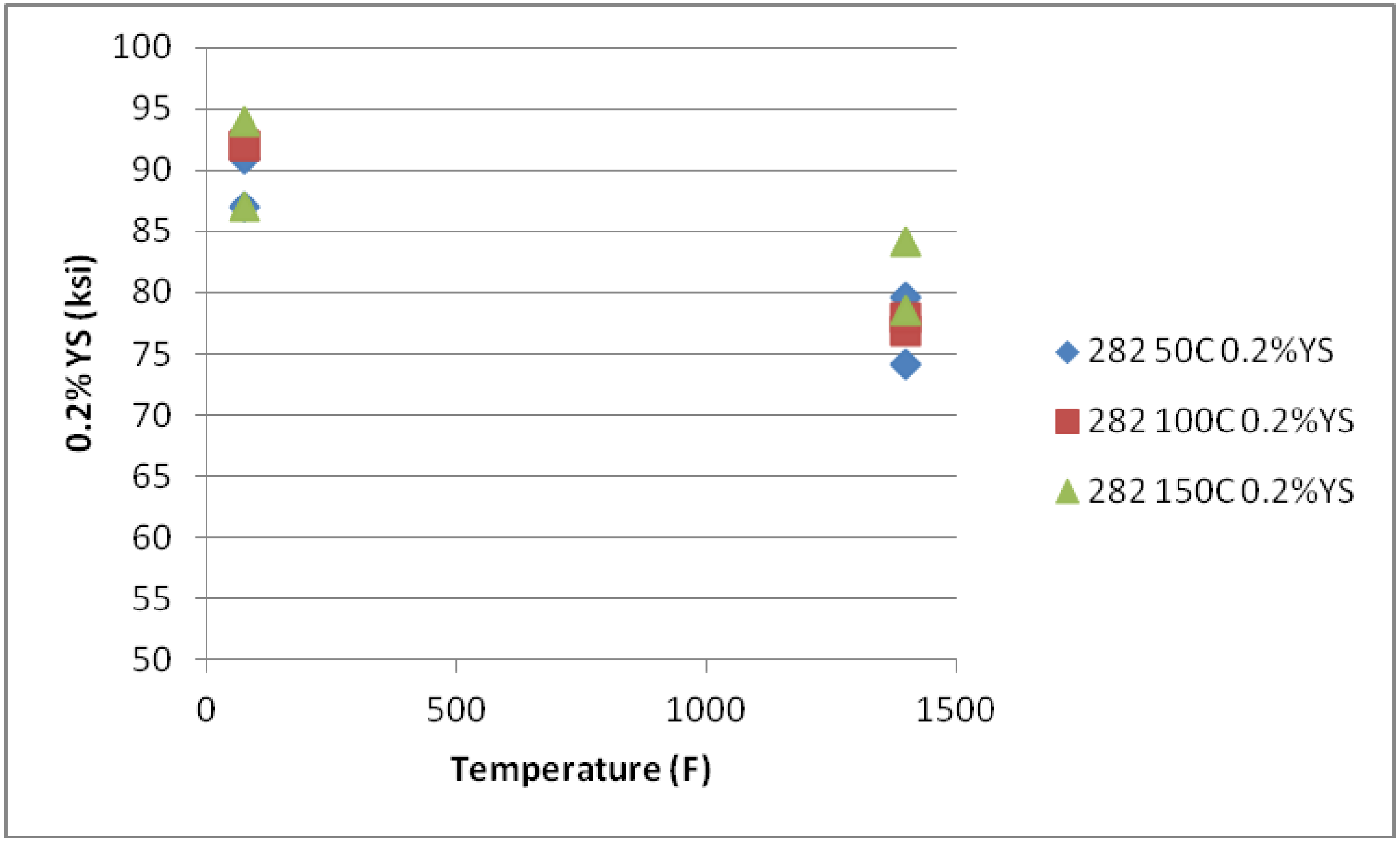
Columnar Region

1 mm

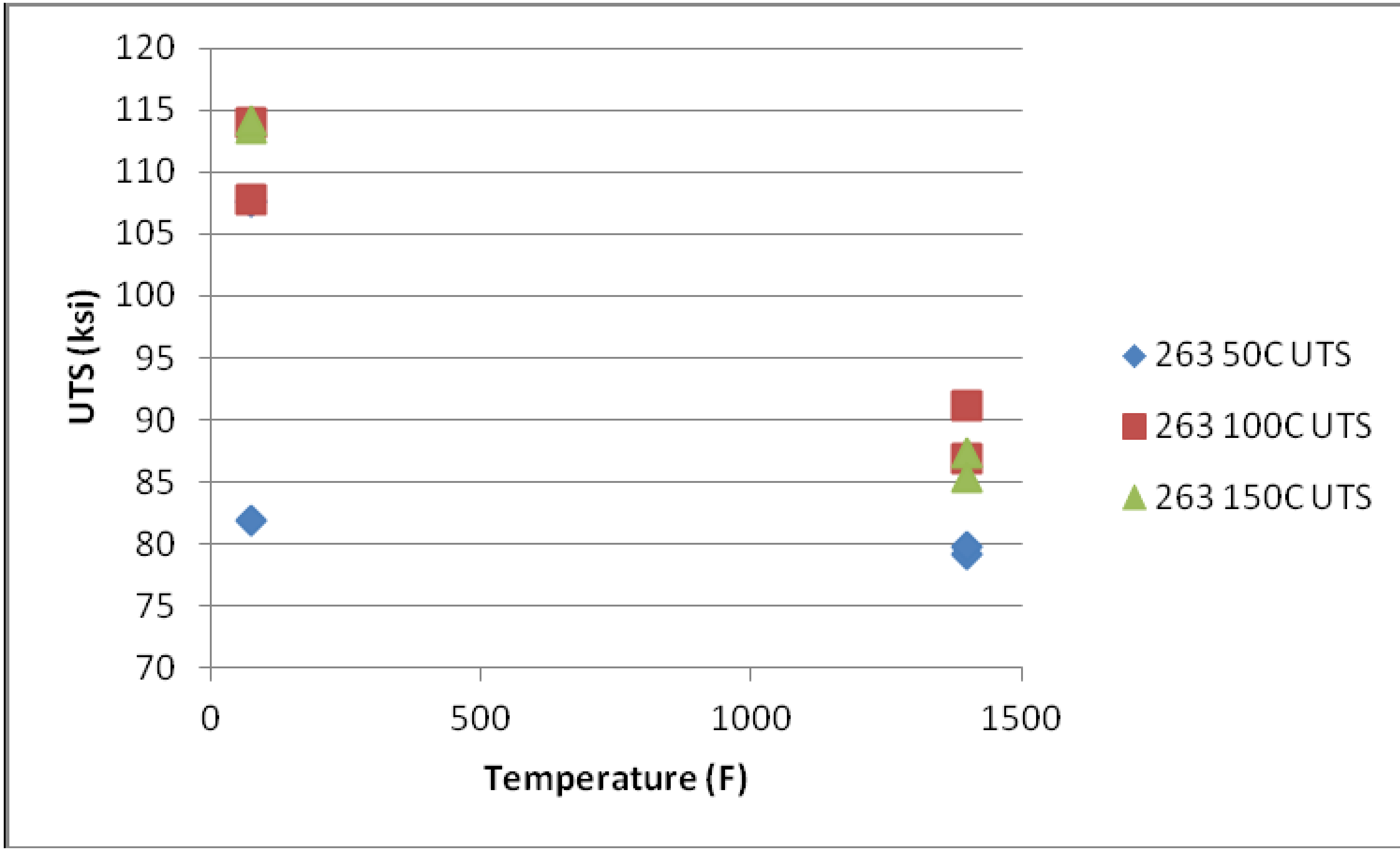
263 Yield Strength Results



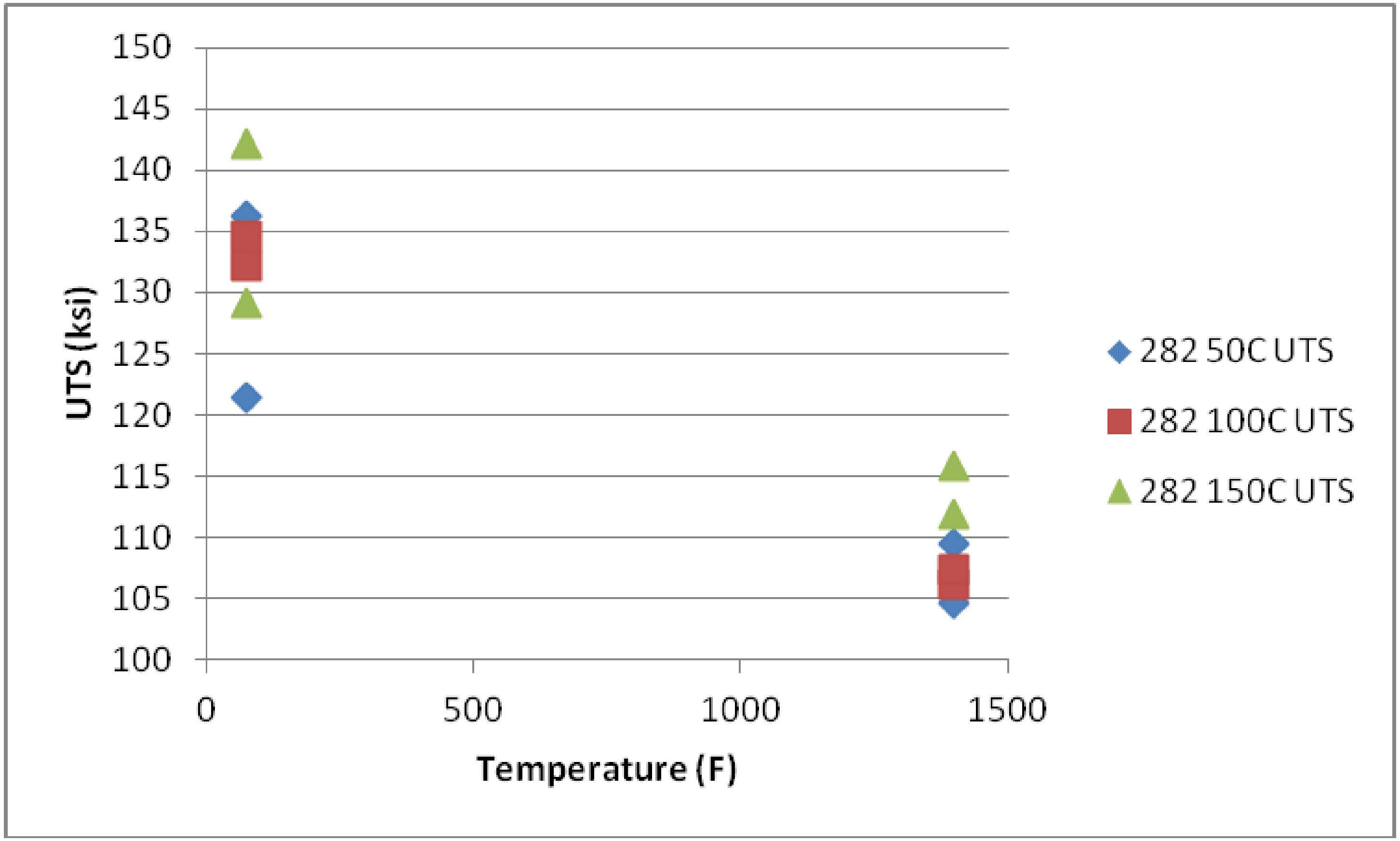
H282 Yield Strength Results



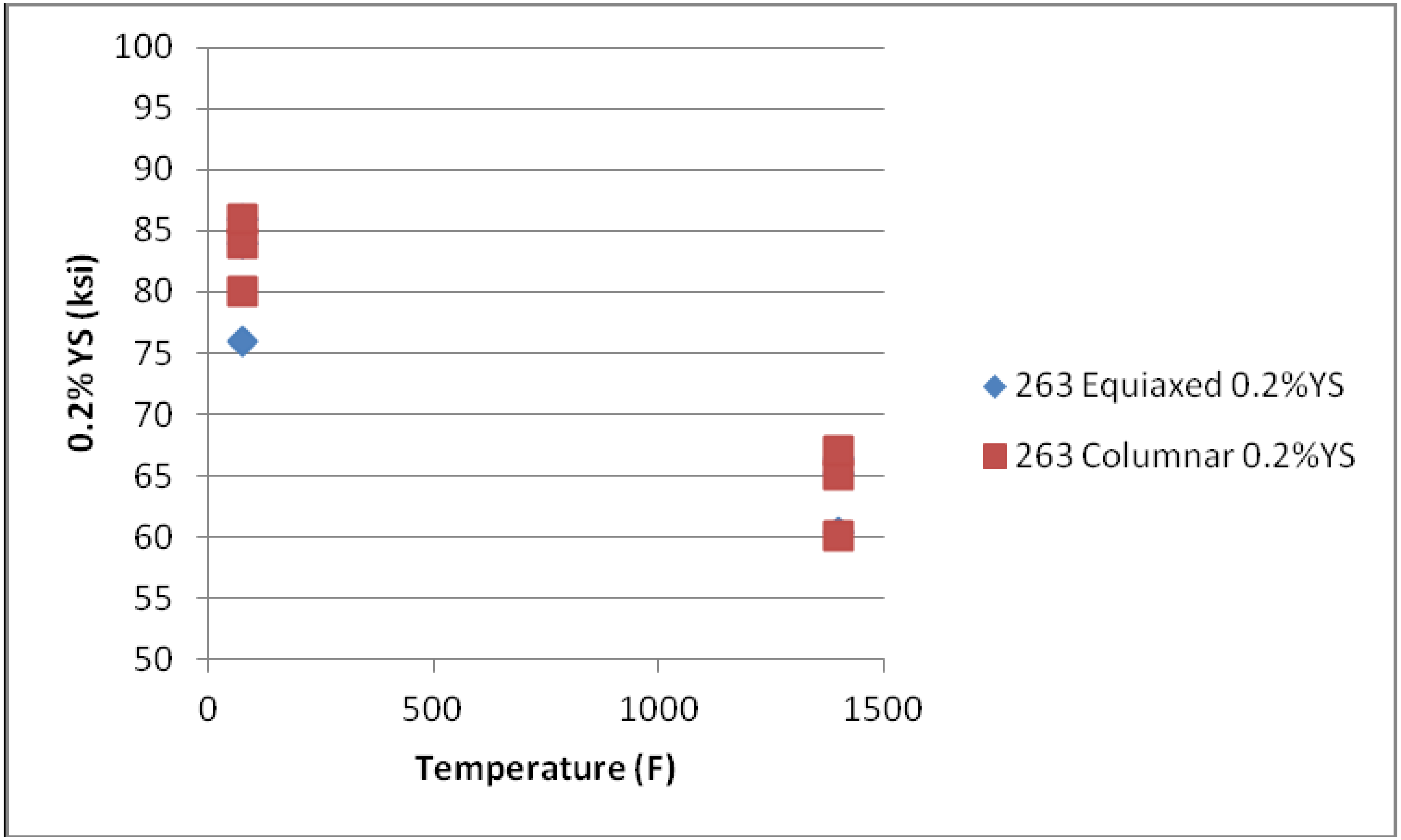
263 Ultimate Tensile Results



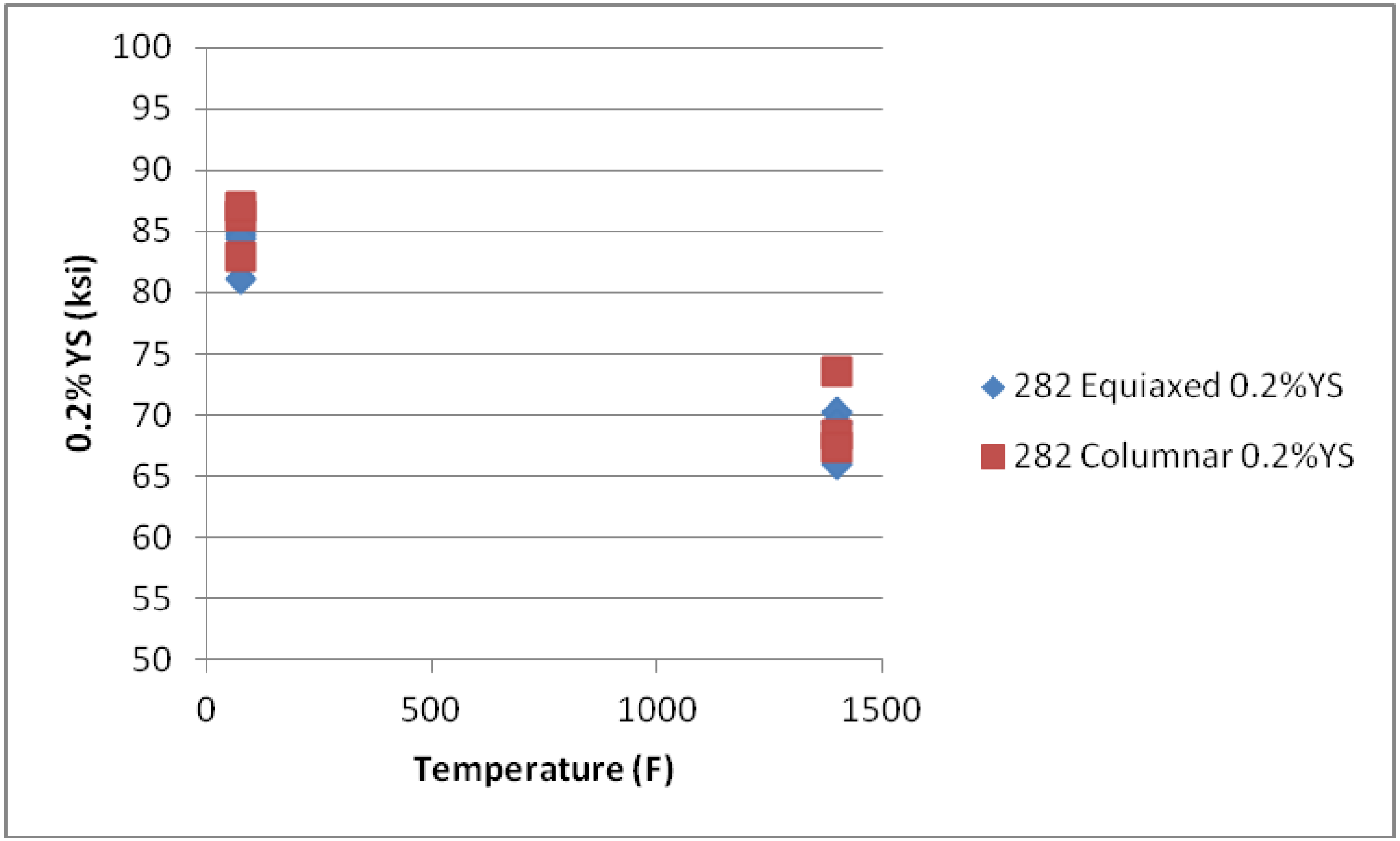
H282 Ultimate Tensile Results



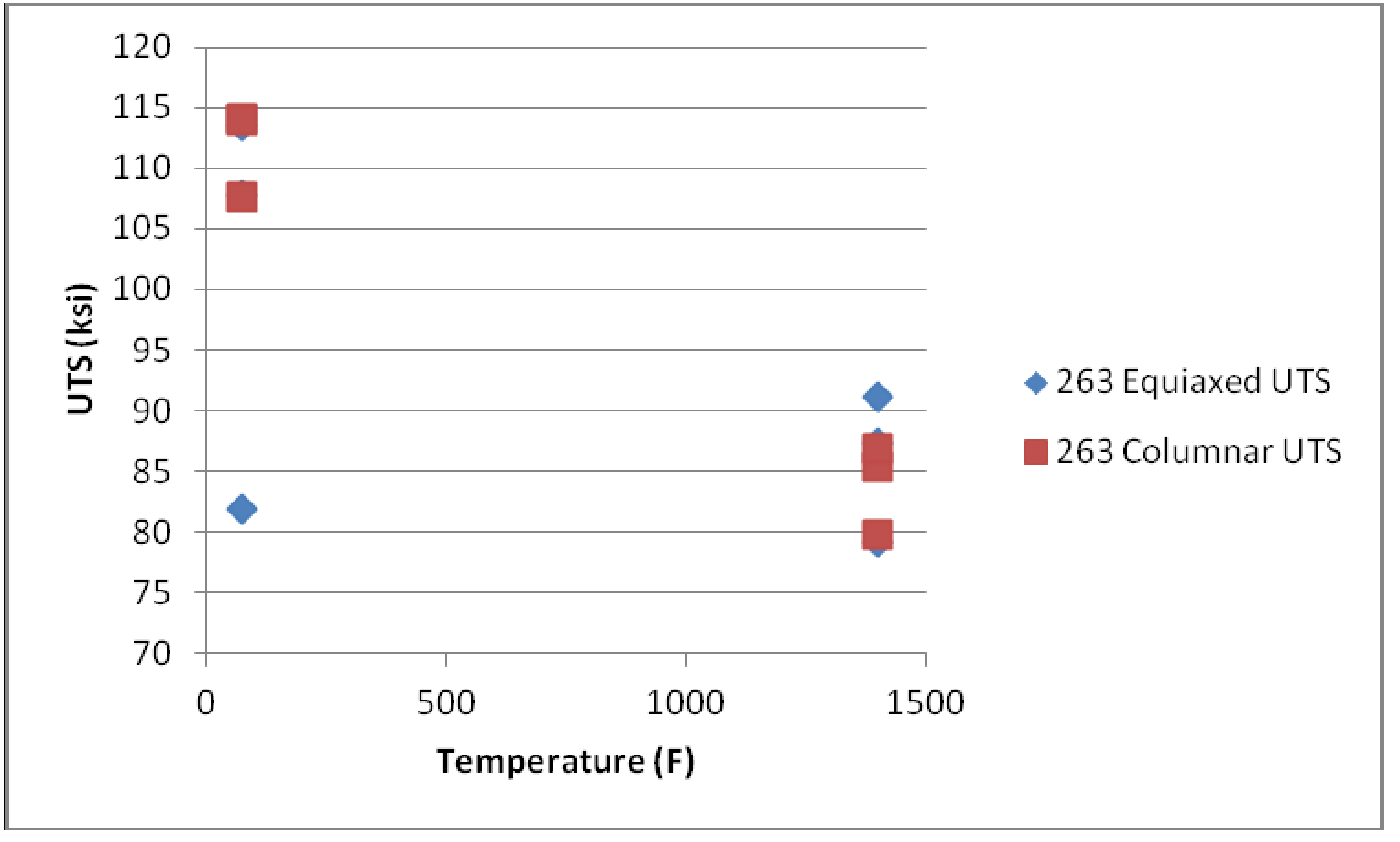
263 Grain Structure Comparison: YS



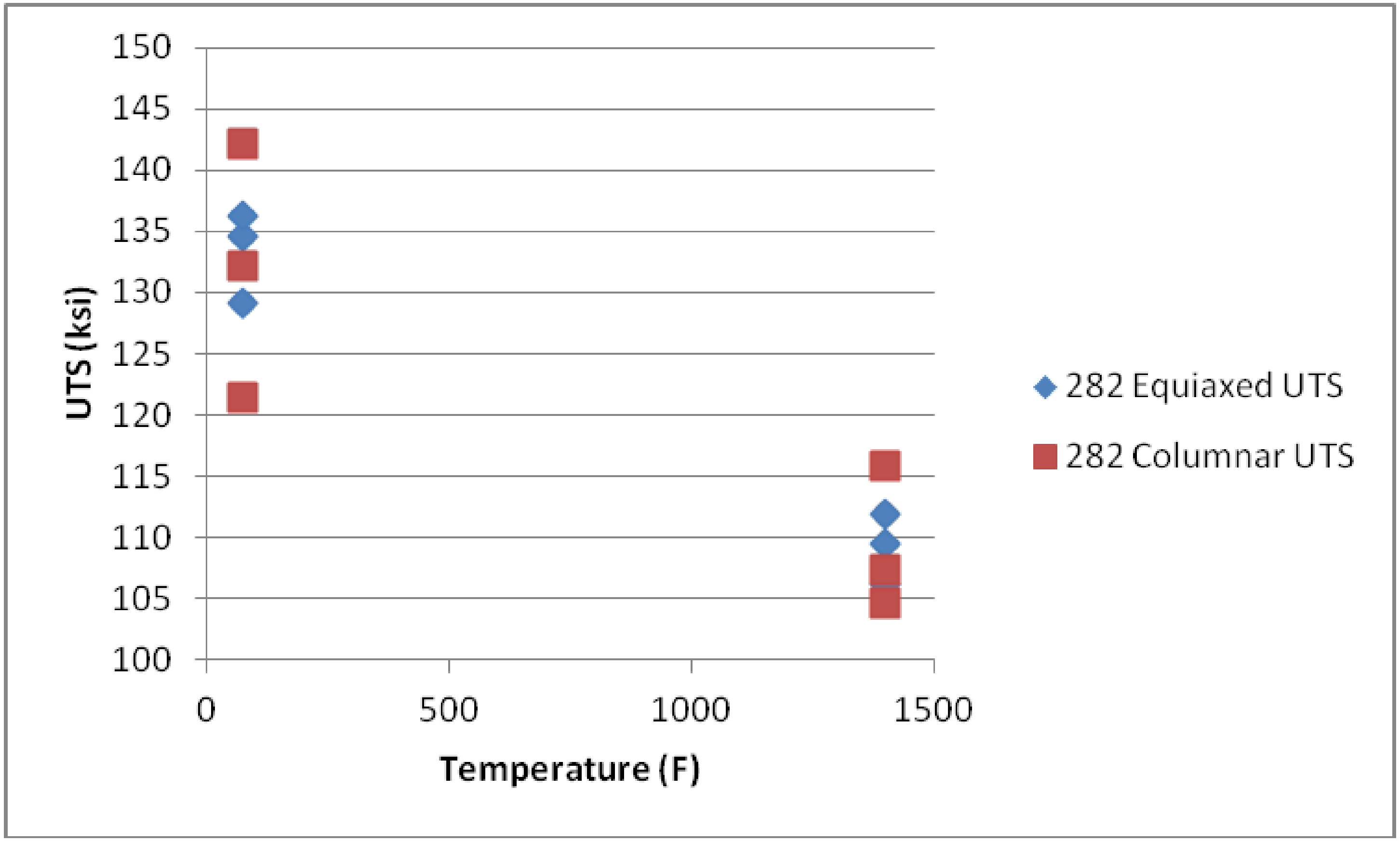
H282 Grain Structure Comparison: YS



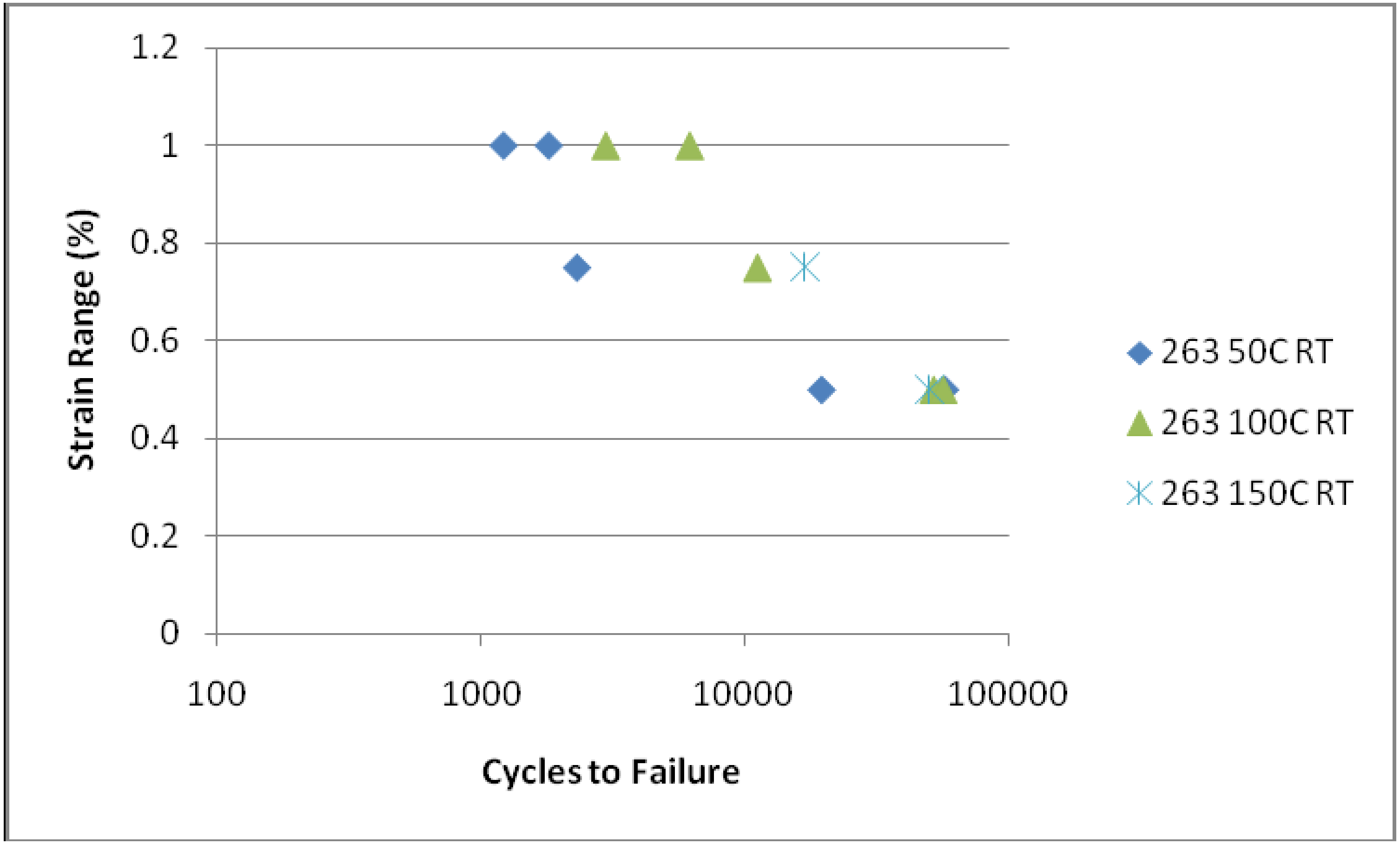
263 Grain Structure Comparison: UTS



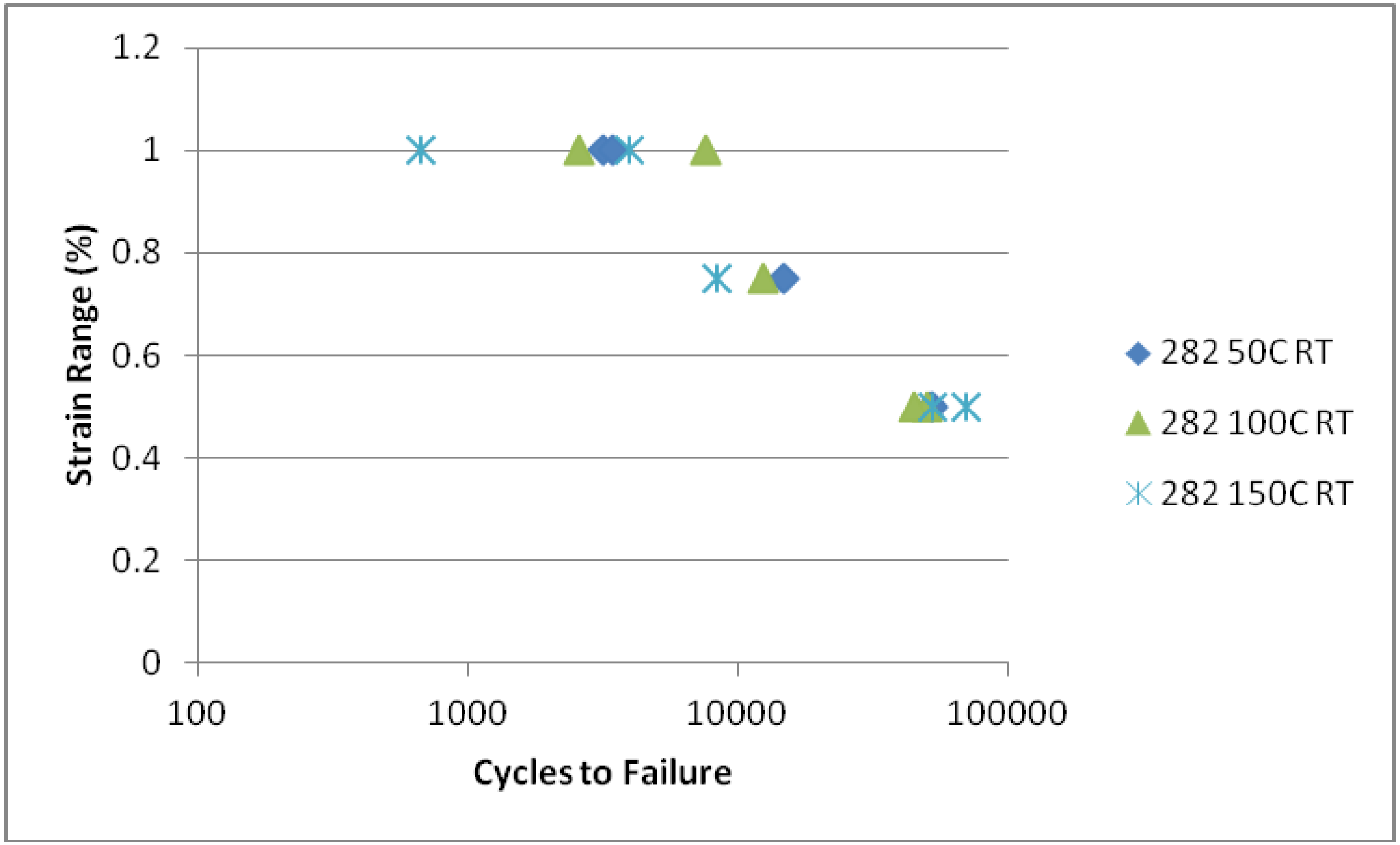
H282 Grain Structure Comparison: UTS



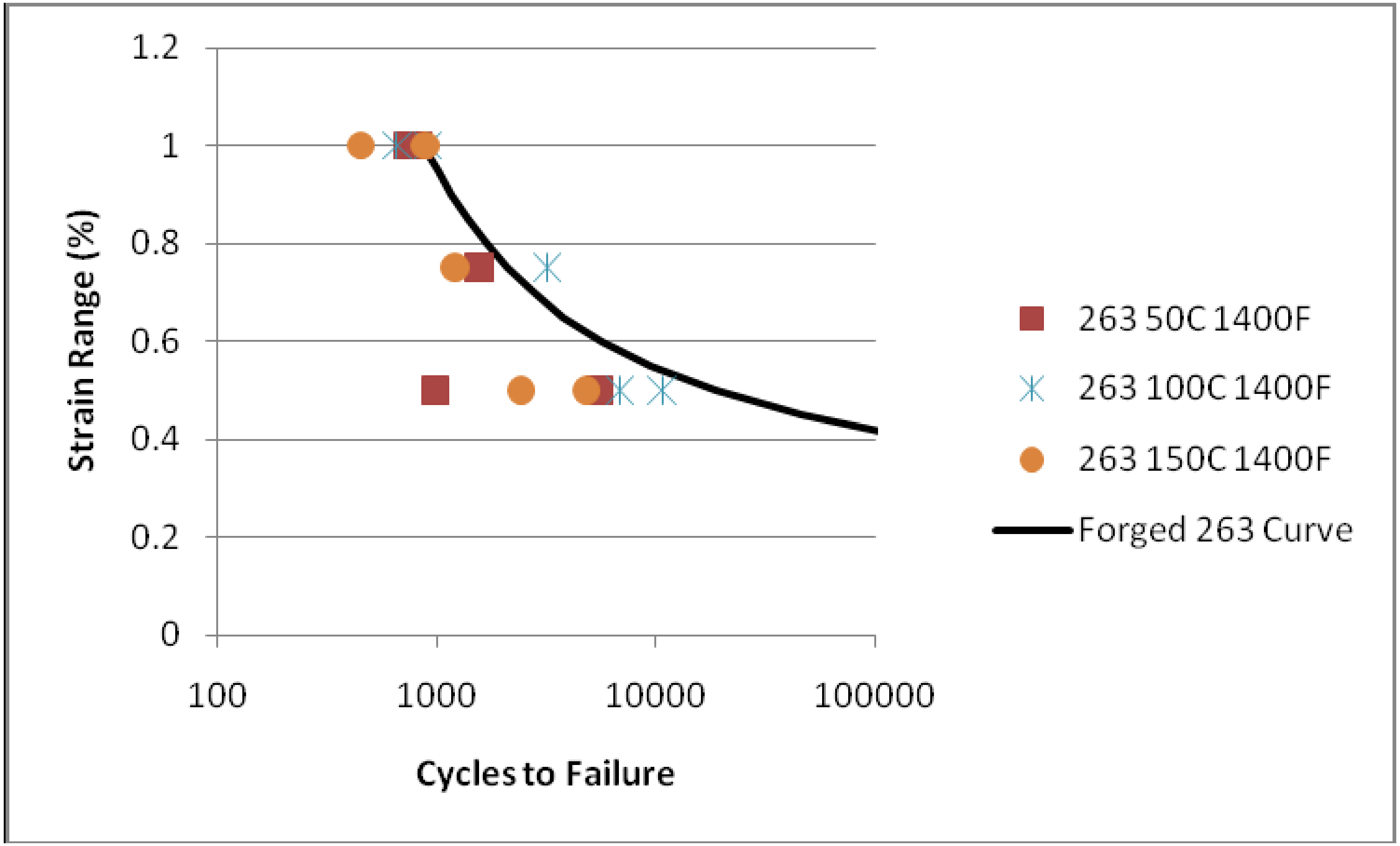
263 Fatigue at Room Temperature



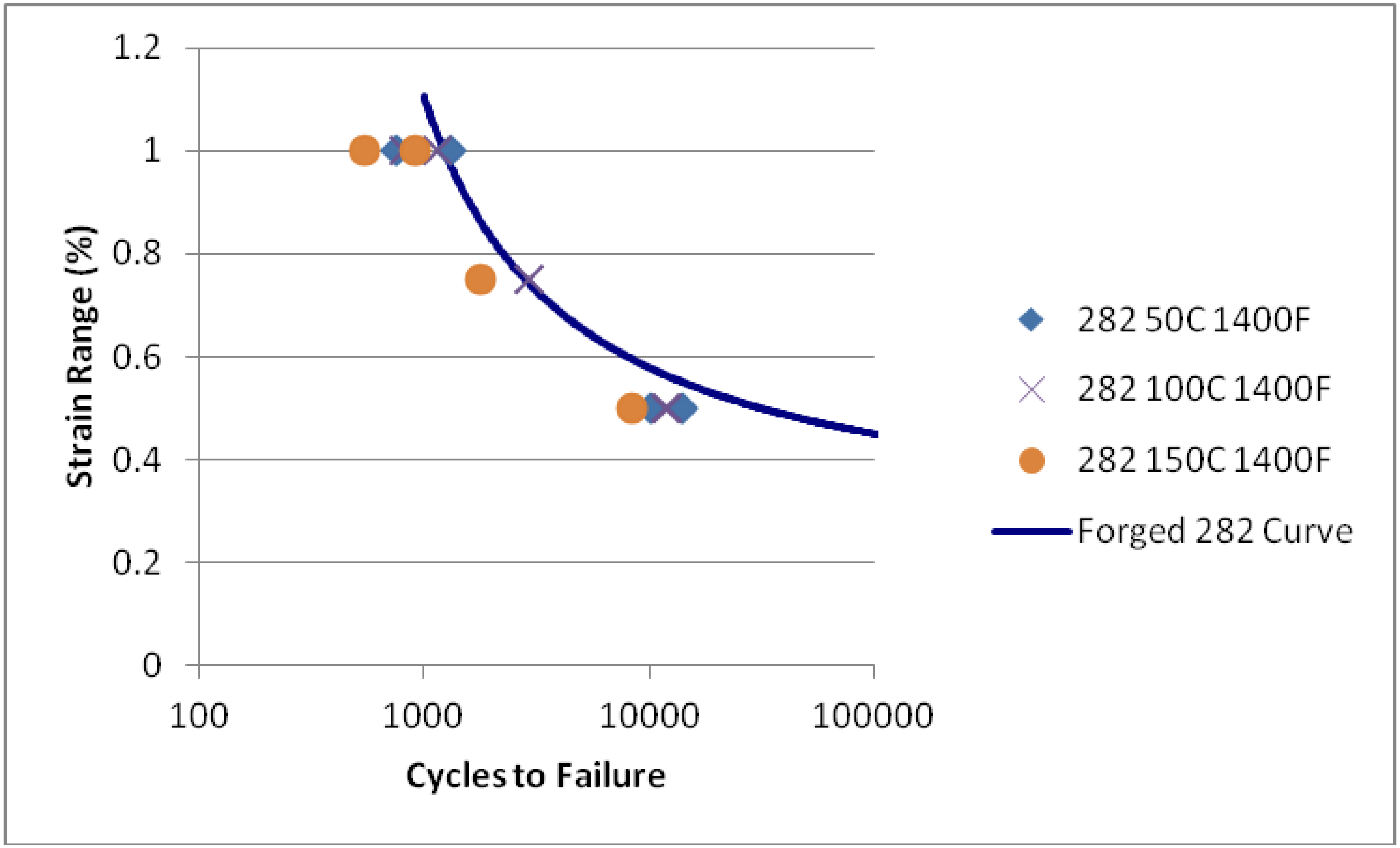
H282 Fatigue at Room Temperature



263 Fatigue at 760C



H282 Fatigue at 760C



Summary

- **A-USC conditions will require advanced Ni-based alloys to operate; alloy 263 and H282 are examined here.**
- **Small scale castings were made to evaluate the performance of cast forms of traditionally wrought alloy 263 and H282 with varying amounts of superheat.**
- **A computationally optimized homogenization heat treatment was developed to improve the performance of these alloys.**
- **The tensile and fatigue performance of these alloys appears to be little effected by varying superheat.**

Summary

- In the tensile properties, both alloys showed a 3-5 ksi increase in UTS for each 50C superheat. In 263, 50C superheat, 0.2% YS is 5-7 ksi lower than the other two; in H282, 0.2% YS is about the same across all three.
- In fatigue, H282 showed no discernible effect of superheat while 263 seems to perform best by a small margin, with a 100C superheat.
- With respect to grain orientation, columnar vs. equiaxed, the two alloys show little to no difference across alloys, test temperatures, and properties.
- The fatigue results compare very favorably to the wrought H282 results gathered in previous work.

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