



Goodwin Steel Castings Ltd (UK)

“Advances in Ni Alloy Casting  
Production for +700°C Applications”



Waikola, Hawaii, 22-25 October 2013

[www.goodwinsteelcastings.com](http://www.goodwinsteelcastings.com)

S.Roberts – Technical Director  
S.Birks – General Manager

## Presentation Structure

1. Introduction
2. What is state of the art in 2013 for Nickel Alloy A-USC Alloy Castings
3. A-USC application castings produced by Goodwin
4. Manufacture of nickel castings
  - Air melting routes
  - Mould filling and oxidation prevention
  - Shrinkage characteristics
  - Solidification stress cracking
  - Goodwin's 'Induction Heating Feeder System'
5. Precipitation Hardened Alloys (750+°C operation)
6. Conclusions

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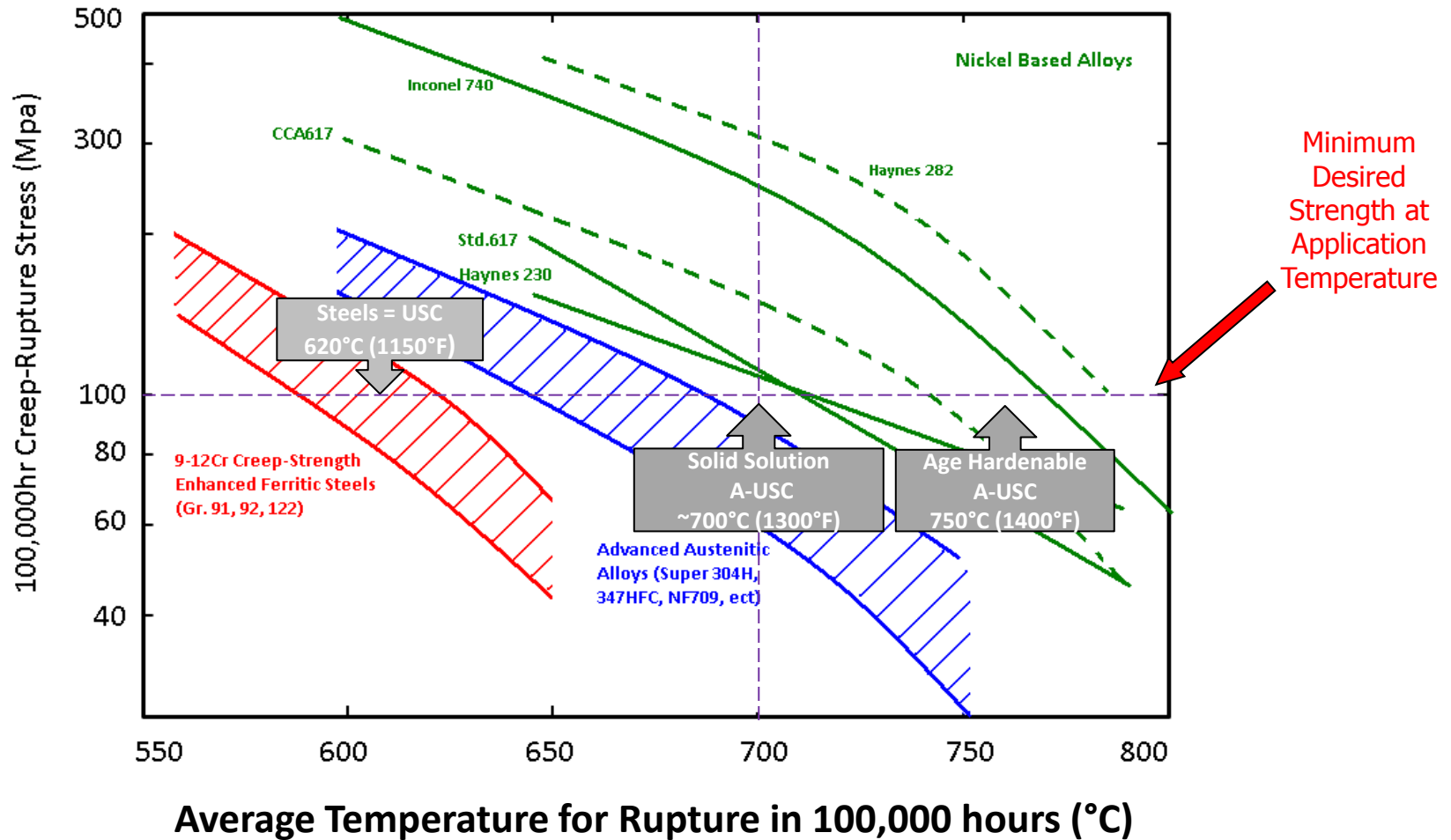
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# 1. Introduction

The drive for reduced carbon dioxide emissions.....



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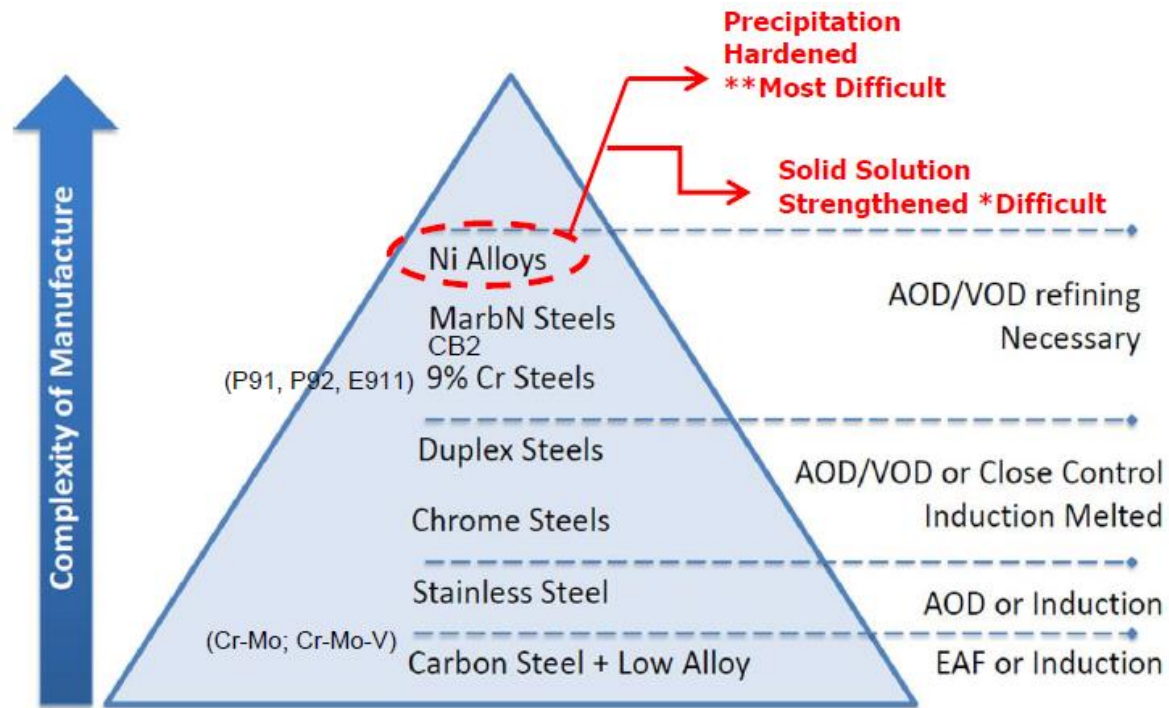
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## 2. What is state of the art in 2013 for nickel alloy A-USC alloy castings?

Full scale 625 components produced in European and Pacific Basin A-USC programs

Full scale prototype precipitation hardened alloy casting scheduled 2014



**Representation of casting material processing/manufacturing complexity**

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### 3. A-USC application castings produced by Goodwin

Alloy Type	Largest unit Weight Single Item Produced	Largest Section Size	Largest Fabrication Weld
Alloy 625	11,000kg	435mm	200mm + 220mm Dissimilar weld
Alloy 617 Mod	1800kg	300mm	55mm
Alloy 263	900Kg	300mm	None
Alloy 282	900kg	300mm	None
Alloy 740	800Kg	330mm	45mm
Alloy 740H	900kg	300mm	None

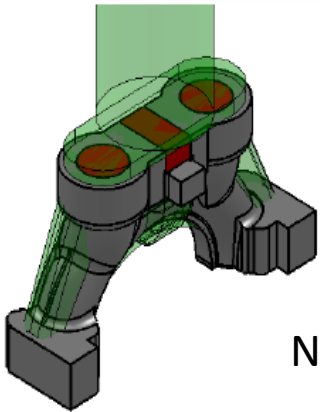


10,500kg Alloy 625 HP Casing manufactured by Goodwin 2011-2012  
Supplied in the proof machined condition with section sizes up to 435mm

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Nozzle box castings produced in Alloy 617-Mod and Alloy 625  
Using the “Induction Heating Feeder System”

Net weight: 1,800kg each

Section size: up to 300mm prior to proof machining

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## 4. Manufacture of nickel castings

### Air melting routes

Nickel alloys by nature contain aluminium and titanium to promote the formation of gamma prime.

These elements have a high affinity for oxygen so action must be taken to prevent low Al/Ti recoveries, oxide films and inclusion defects.

The preferred route is primary melting followed by secondary AOD melting



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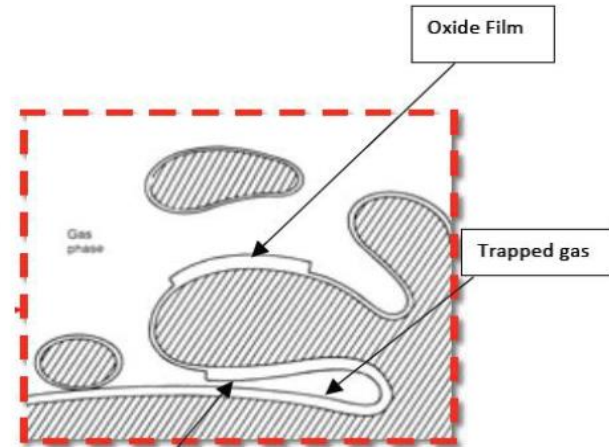
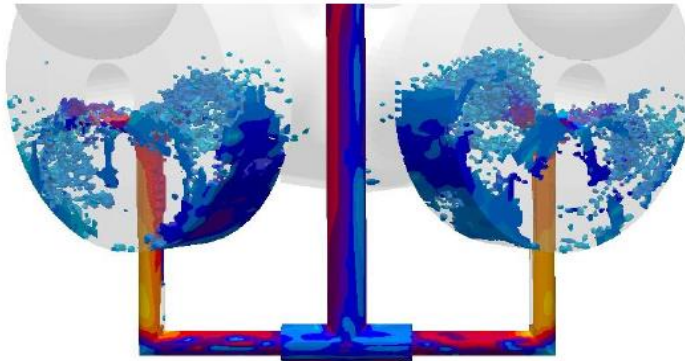


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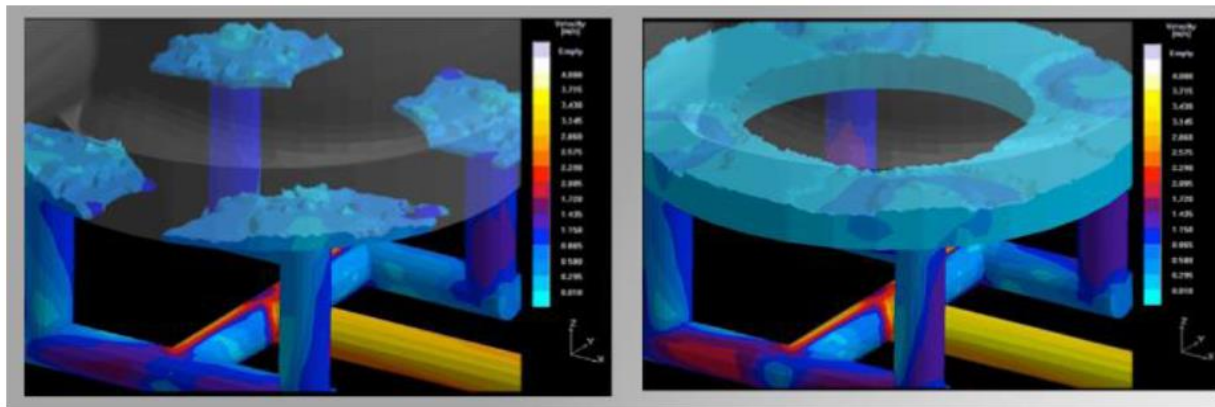
## 4. Manufacture of nickel castings

### Mould filling and oxidation prevention

#### Example of Pour Filling Design



#### Example of Good Filling Design

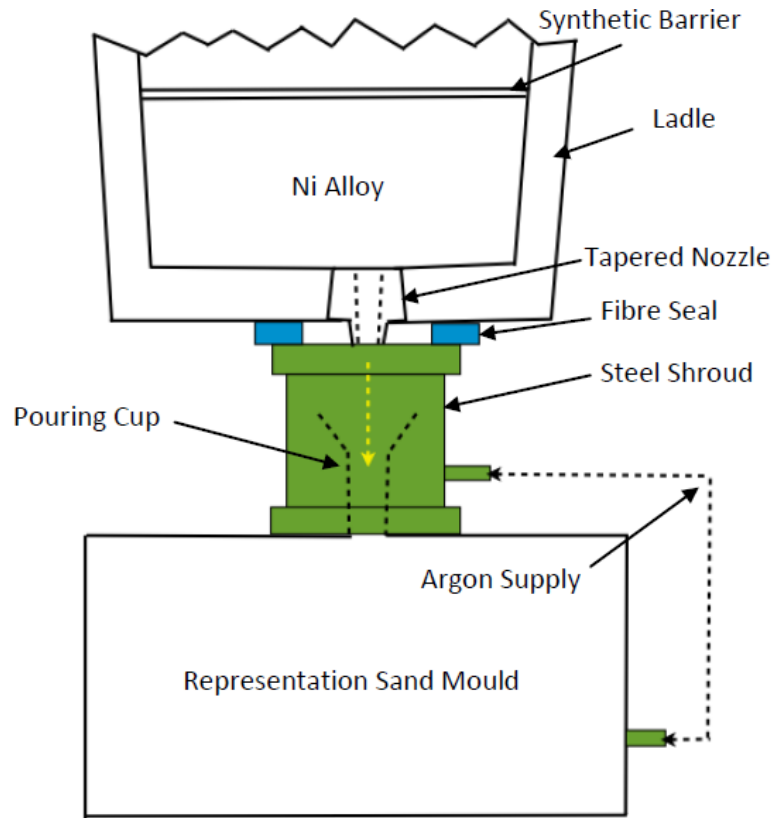


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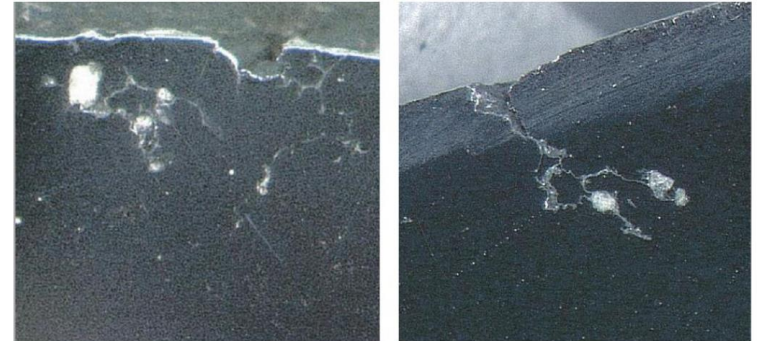
## 4. Manufacture of nickel castings

### Mould filling and oxidation prevention

#### Goodwin's "Total Emersion System (TES)"



#### Oxide Defects in Ni Alloys



These oxide defects are associated with reoxidation of Aluminum



This system seals the ladle stream from air, and therefore prevents oxidation. Argon is also purged into the mould both before and during the pouring operation.

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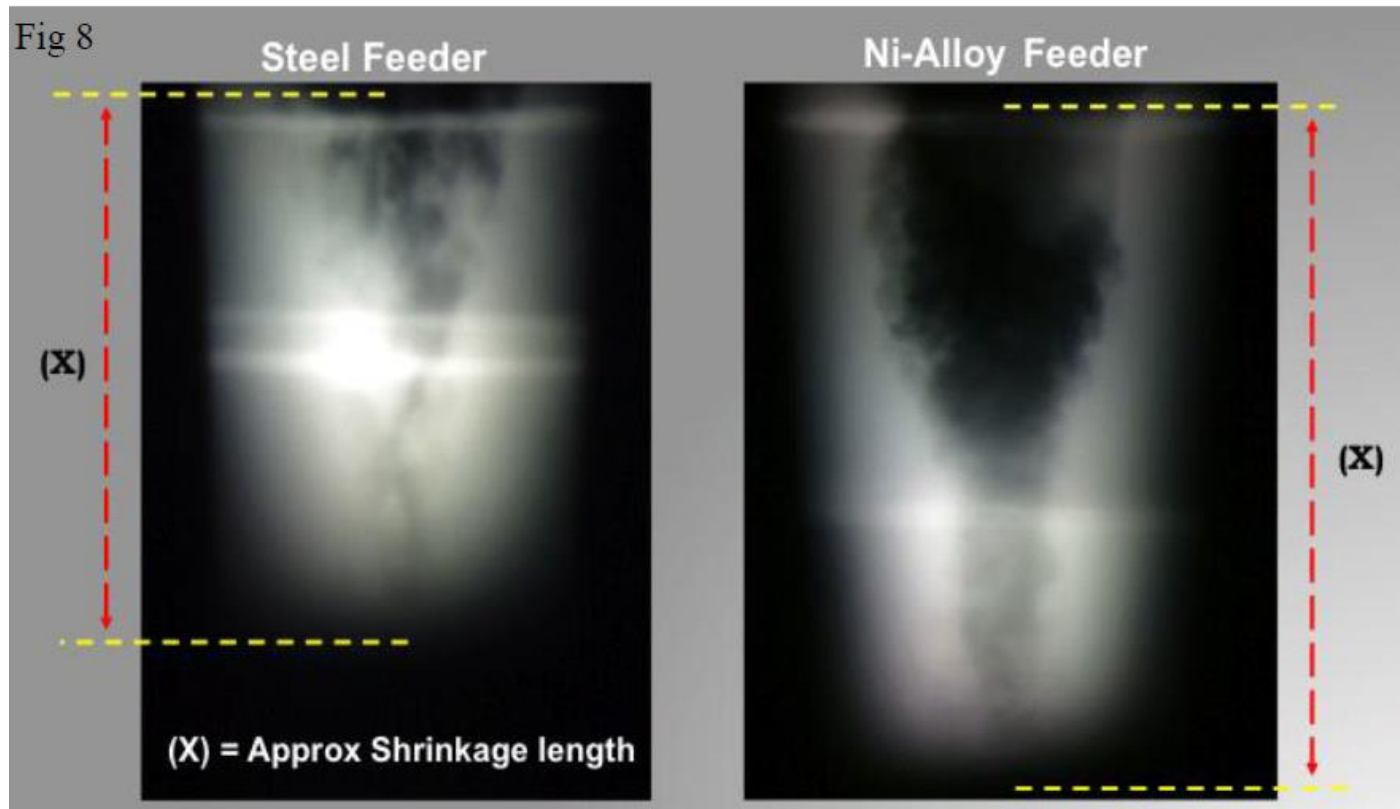
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## 4. Manufacture of nickel casting

### Shrinkage characteristics

Nickel alloys have different shrinkage characteristics than conventional steels



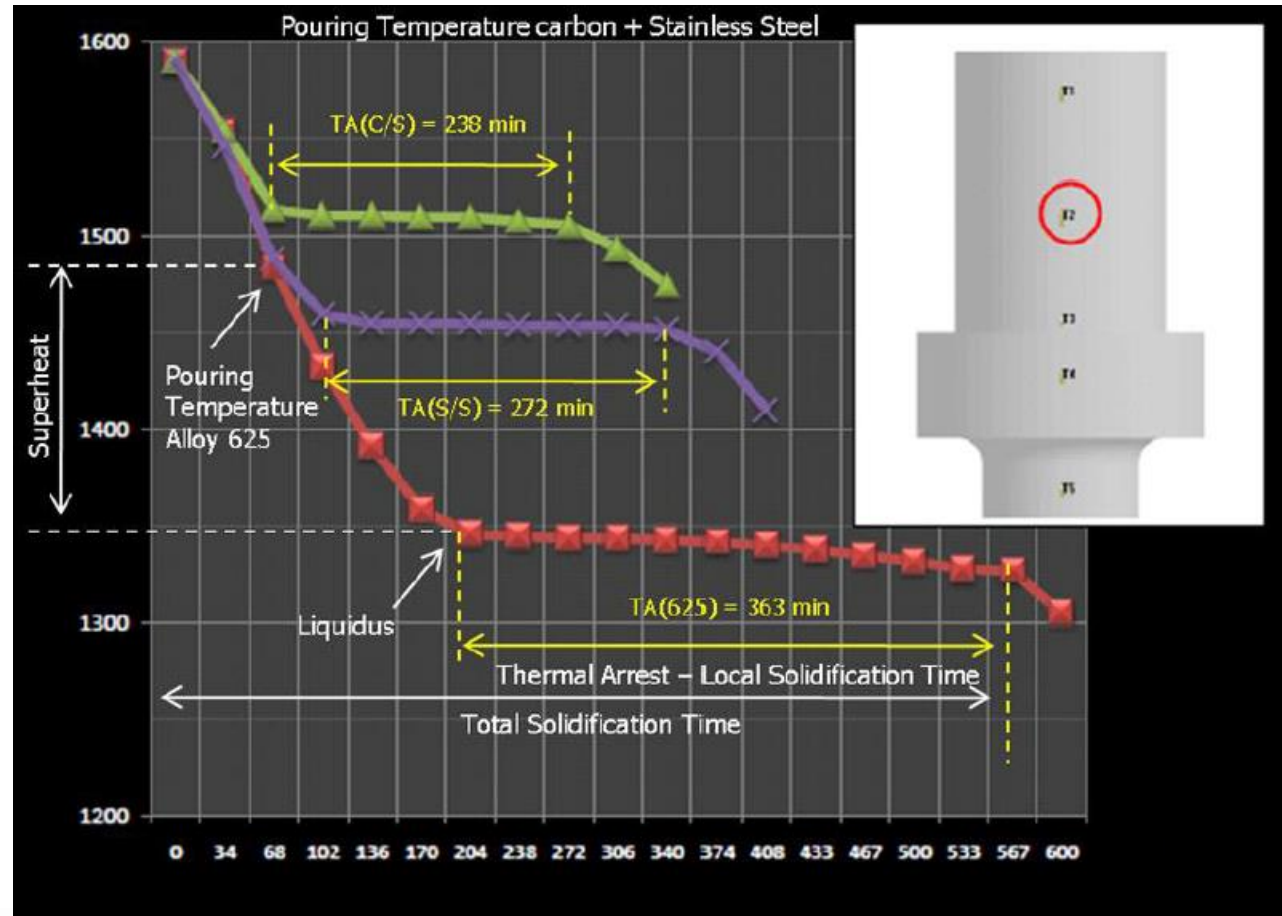
**25% increase in  
feeder pipe length**

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# 4. Manufacture of nickel castings

## Shrinkage characteristics

Alloy	Estimated Liquid Shrinkage	Equilibrium Freezing range	Super Heat above Liquidus
Carbon Steel	5.5%	65°C	70°C
Stainless Steel	5.8%	55°C	100°C
Alloy 625	7.9%	60-70°C	150°C
P91 9% Cr Steel	5.2%	85°C	90°C



Why is it so different?

- A. Thermal Conductivity
- B. Freezing range
- C. Liquid shrinkage characteristics

Out of the box solidification packages require extensive in-house calibration!



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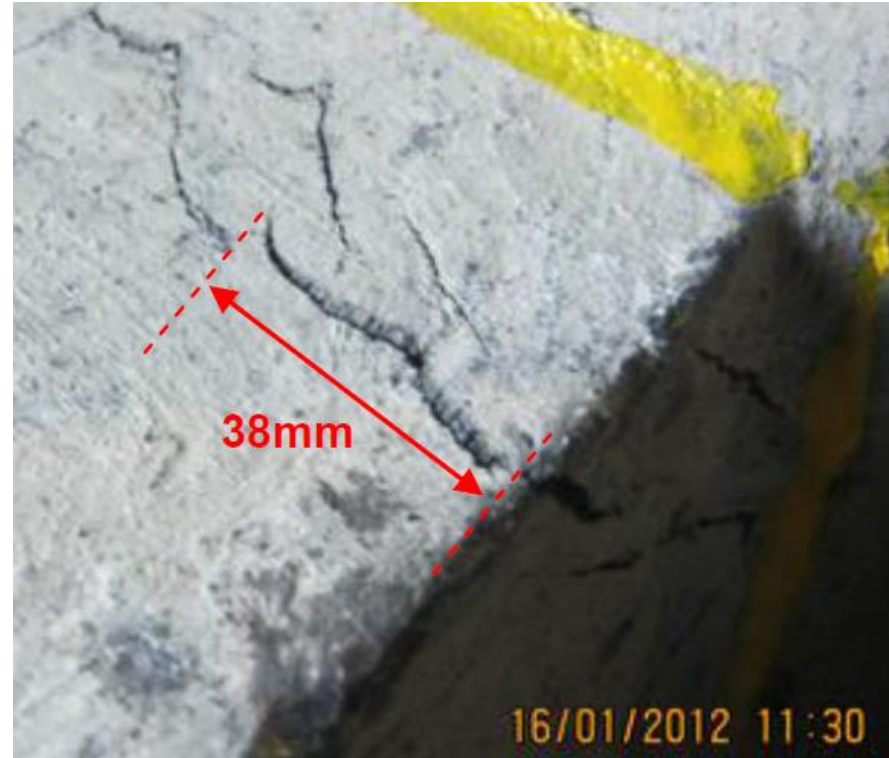


## 4. Manufacture of nickel castings

### Solidification stress cracking

Far more prevalent in nickel alloys compared to conventional steels

- Poor thermal conductivity
- Solidification stresses
- Section sensitive



*Example of solidification cracks seen after knock out of a modified Alloy 617*

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## 4. Manufacture of nickel castings

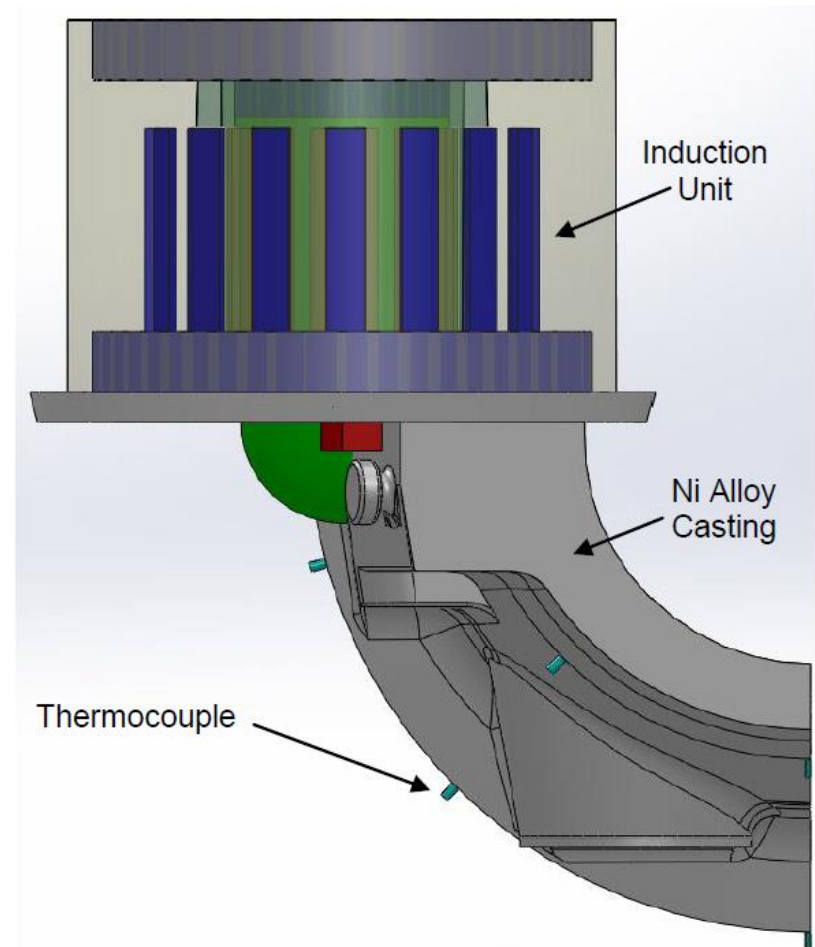
### Goodwin's "Induction Heating Feeder System"

#### Specifically designed for Nickel Alloy castings

- Induction coil surrounds the feeder heads
- Allows heating of the molten metal
- Control the solidification characteristics

#### Benefits

- Reduced solidification stresses to prevent stress cracking
- Allow reduced feeder size
- Yields increased up to 75%, conventionally 40%-50%
- Reduced feeder pipe length



*Schematic of one of the induction units placed around a feeder of a turbine casing*

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## 5. Precipitation Hardened Alloys (750+°C operation)

Next generation alloys for A-USC application

Strengthened by the precipitation of  $\gamma'$  /  $\gamma''$  when aged  $\approx 800^\circ\text{C}$

Aerospace heritage – unproven in cast heavy section

High Al + Ti – Requires oxidation protection



**Alloy 263**

**Inconel<sup>®</sup> 740H**

**Haynes<sup>®</sup> 282<sup>®</sup>**

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## 5. Precipitation Hardened Alloys (750+°C operation)

### Step blocks produced

	C	Si	Mn	Ni	Cr	Mo	Nb	Co	Al	Ti	Fe
Inconel <sup>®</sup> 740	0.047	0.21	0.24	Bal	25.8	0.38	1.39	20.62	0.94	2.16	0.66
Inconel <sup>®</sup> 740H	0.046	0.32	0.30	Bal	24.6	0.54	1.31	19.57	1.22	1.36	0.22
Haynes <sup>®</sup> 282	0.034	0.36	0.03	Bal	19.3	8.01	0.03	10.0	1.40	2.10	0.21
Alloy 263	0.057	0.34	0.37	Bal	19.8	5.61	0.01	19.6	0.42	2.05	0.07



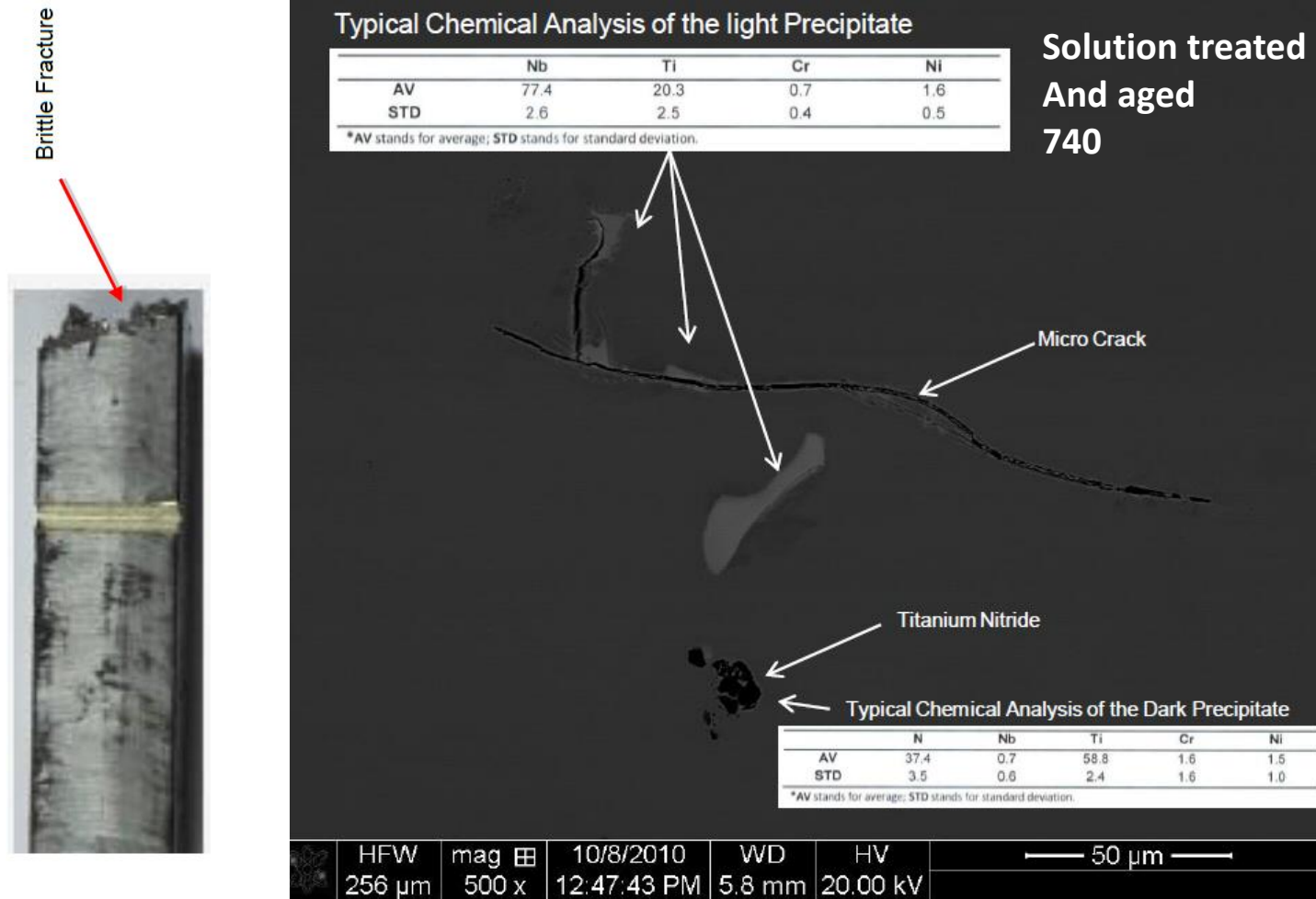
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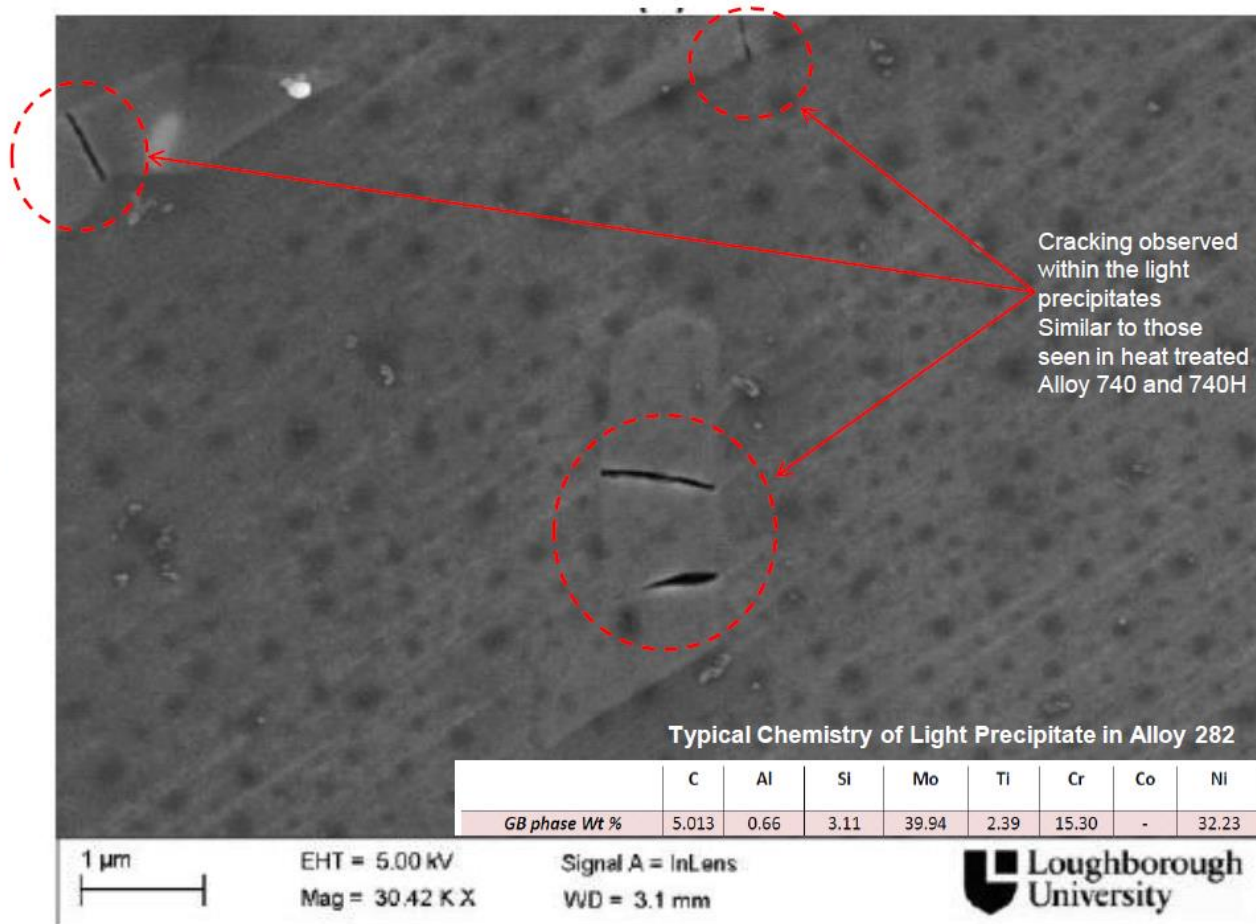
## 5. Precipitation Hardened Alloys (750+°C operation)

All the blocks, to an extent, had volumetric cracking in the heavy sections after heat treatment



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## 5. Precipitation Hardened Alloys (750+°C operation)



**Cracking can not be avoided by heat treatment**

**Alloy optimisation required**

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## 5. Precipitation Hardened Alloys (750+°C operation)

2013

Three new alloys cast  
early results look promising

**Alloy 263-Mod**

**Haynes®282®-Mod**

**Goodwin variant Ni alloy**



Alloy	UTS (N/mm <sup>2</sup> )	Yield (N/mm <sup>2</sup> )	Elongation (%)	R of A (%)	Impacts @ RT (J)
Inconel®740	600	575	4	10	36/28/46 Avg 37
Inconel®740H	560	545	5	11.5	22/43/37 Avg 34
Alloy 263	496	444	9	-	-
Haynes® 282®	No result – samples fractured early – no results could be obtained				
Goodwin variant	691	410	30	42	128/136/110 Avg 125
Haynes®282® MOD	751	588	15	18	52/50/50 Avg 51
Alloy 263 MOD	718	506	29	28	150/184/205 Avg 180

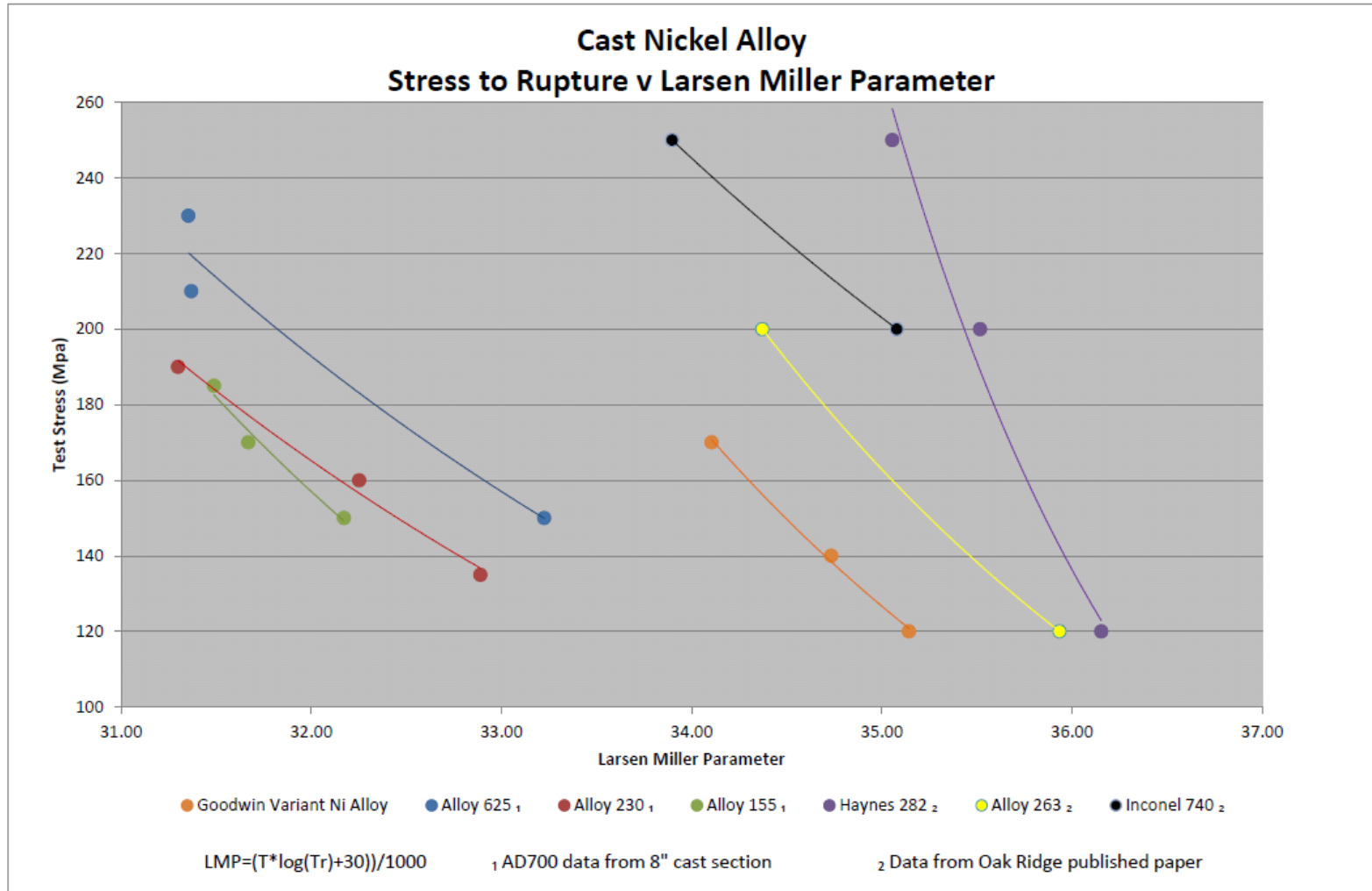
After solution HT and aged at 800°C for 8 hrs

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## 5. Precipitation Hardened Alloys (750+°C operation)



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## 6. Conclusions

15 years of cast nickel alloy R&D

### Ni alloys for 700°C application

- Successfully produced heavy section Alloy 625 and 617 castings
- Full scale castings are a commercial reality

### Ni alloys for 750+°C application

- Forefront in this field
- Modified alloys produced
- Technical issues to be addressed
- Optimisation of heat treatments for  $\geq 300\text{mm}$  section thicknesses being developed

### 2014

- Further optimisation of the modified nickel alloys plus Goodwin's variant cast nickel alloy
- Produce the worlds largest precipitation hardened casting for prototype A-USC technology



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# Thank you for listening



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