Applications of Thermo-Calc and DICTRA

Thermo-Calc Users Meeting
Aachen, 2010-09-09

Sebastian Piegert
E F PR GT EN M&T MPD3

Copyright © Siemens AG 2009. All rights reserved.
Outline

- Introduction
- Siemens Gas Turbines
- Applications of Thermo-Calc and DICTRA
  - Base Material Characterisation
  - Braze Alloy Development and Heat Treatment Optimisation
  - Heat Treatment for a Welding Process
- Summary
Introduction
Structure of Siemens

Industry

Healthcare

Energy

Source: Siemens

Copyright © Siemens AG 2009. All rights reserved.

Page 3  2010-09-09  Sebastian Piegert  Siemens Energy Sector F PR GT EN M&T MPD3
Introduction
Structure of Siemens Energy

Products and Solutions for Energy – in 6 Divisions

- Oil & Gas
- Fossil Power Generation
- Renewable Energy
- Energy Service
- Power Transmission
- Power Distribution
Introduction
Overall Vision of Siemens Energy Sector
Siemens Gas Turbines
Portfolio

Large Gas Turbines

<table>
<thead>
<tr>
<th>Model</th>
<th>Value (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGT5-8000H</td>
<td>375</td>
</tr>
<tr>
<td>SGT5-4000F</td>
<td>292</td>
</tr>
<tr>
<td>SGT6-5000F</td>
<td>200</td>
</tr>
<tr>
<td>SGT6-4000F</td>
<td>187</td>
</tr>
<tr>
<td>SGT5-2000E</td>
<td>168</td>
</tr>
<tr>
<td>SGT6-2000E</td>
<td>113</td>
</tr>
</tbody>
</table>

Industrial Gas Turbines

<table>
<thead>
<tr>
<th>Model</th>
<th>Value (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGT-800</td>
<td>47</td>
</tr>
<tr>
<td>SGT-700</td>
<td>30</td>
</tr>
<tr>
<td>SGT-600</td>
<td>25</td>
</tr>
<tr>
<td>SGT-500</td>
<td>17</td>
</tr>
<tr>
<td>SGT-400</td>
<td>13</td>
</tr>
<tr>
<td>SGT-300</td>
<td>8</td>
</tr>
<tr>
<td>SGT-200</td>
<td>7</td>
</tr>
<tr>
<td>SGT-100</td>
<td>5</td>
</tr>
</tbody>
</table>

Values in MW @ ISO Conditions
Siemens Gas Turbines
SGT5-4000F (V94.3A) Gas Turbine

- Compressor, 15 stage with CDA airfoils in all stages and with side-wall correction. One variable guide vane row. Developed with P&W.
- Annular combustion chamber with 24 hybrid burners. Hot gas path with air cooled metallic or ceramic heat shield.
- 4-stage turbine
  - Blade 1 and 2 single crystalline and directionally solidified
  - Film-cooling of blades and vanes of stage 1 and 2
- Rotor with Hirth serration and single tie bolt. Quick thermal response because of rotor internal flow passages.

- Excellent thermal balance due to:
  - Quick and stiff rotor
  - Conical turbine flow path
- Due to thermal balance:
  - Quick start up
  - Hot restart capability
Siemens Gas Turbines
Air Cooled Turbine Blades and Vanes

γ’ precipitation hardened
Ni-based Superalloy

2 μm

© Siemens AG 2009. All rights reserved.

Copyright © Siemens AG 2009. All rights reserved.
Siemens Energy Sector F PR GT EN M&T MPD3
Applications of Thermo-Calc and DICTRA

Thermo-Calc Version S with TTNi 7 Database
DICTRA 25 with MobNi1 Database
Base Material Characterisation – IN 738 LC

Possible Calculations:
- solvus temperatures
- amount of phases with respect to temperature
- phase compositions
- prediction of occurrence of detrimental phases such as s, h etc.

Applications:
- estimation of “allowed” service temperatures
- definition of heat treatments
- influence of material non-conformances in regard to composition can be evaluated
Development of a Boron Free Braze

Scope:
- Develop a boron free braze alloy to avoid formation of brittle phases.

Approach:
- use Ge as MPD
  - high solubility in Ni
  - forms a to $\gamma'$ isomorphous phase ($\beta$-Ni$_3$Ge)

Problem:
- limited availability of phase diagrams
- Ge not in database (TTNi7)
Development of a Boron Free Braze
Braze Alloy Development

**Issue:**
- Ge braze BfBX-5 with X wt.-% MPD
- low melting eutectics, condensed $\gamma'$ and TCP phases remain in joint
- poor mechanical properties at 850 °C

**Action:**
- new alloy based on René 80
- Y wt.-% Ge are adequate for a liquidus lower than 1200 °C
- detrimental blocky phases and condensed $\gamma'$ were found within joint
- refinement by means of TCC

**Conclusion and Result:**
- reduction of refractory metals Mo/W
- reduction of $\gamma'$ formers
- microstructure is now homogeneous
Development of a Boron Free Braze Heat Treatment Development

Issue:
- appropriate braze cycle not available

Model:
- problem with moving interface
- start of calculation with $L$ (braze) and $\gamma$ (René 80)
- expected phases attached to lower interface, i.e. joint centre, as inactive
- $w_0 = 200 \, \mu m$

Result:
- isothermal single phase solidification of old braze (BfBX-5) within 22 h
- significant reduction of $t_{iso}$ with René 80 based braze
- formation of Laves if $T_{hold}$ is significantly lowered
Weldability of Superalloys

- high temperature strength – $\gamma'$
  $\text{Ni}_3(\text{Al,Ti})$
- corrosion and oxidation resistant

**BUT very prone to cracking**
- in HAZ during welding (hot cracking)
  - solidification cracking
  - cracking due to remelting
  - hot cracking due to loss in ductility
- strain age cracking

**Generally:**
- high $\gamma'$-content = highly prone to cracking
  - $3 \text{ Gew.-%} \leq c_{\text{Al}} + \frac{1}{2} c_{\text{Ti}}$
  - Ta, Nb, Hf form also $\gamma'$
Increase of Weldability

- Low heat input
  - Beam welding (Laser, EB)
    - Micro-Plasma-Powder-Welding
    - Optimisation of welding parameters
  - Pre-heat treatment (solutioning, overageing)
  - Subsequent heat treatment
    - Hotbox-Welding
- Heat treatment
- Weld-fillers
  - Ductile weld-fillers
    - (IN 625, IN 617, Hastelloy X)
Fact: $\gamma'$ precipitation causes shrinkage and hence induces tensile stresses which can lead to cracking of weld deposition.

Question: What heating rate is favourable to avoid strain age cracking?

Solution: $\min \dot{V}_{5 \text{ min} \leq T \leq 20 \text{ K/min}}$

Result:
- low heating rate shall be applied
- high heating rates led to a shift of precipitation to higher temperatures resulting in altered growth rate
- total volume fraction precipitated deviates by only 10\%
Summary

Major Advantages:
- speed up of investigations and decrease time to market
- reduction of experimental testing
- “long term trials” within hours/days
- definition of process windows even of unknown systems possible
- calculation of stable and metastable “real“ systems
- versatile: any type of calculation which is related to thermodynamics and/or kinetics can be thought of
- influence of distinct parameters on the system can be studied separately

Disadvantages:
- non-validated material systems might give inappropriate results
- some knowledge about the systems is required
- mechanical properties cannot be predicted
Disclaimer

This document contains forward-looking statements and information – that is, statements related to future, not past, events. These statements may be identified either orally or in writing by words as “expects”, “anticipates”, “intends”, “plans”, “believes”, “seeks”, “estimates”, “will” or words of similar meaning. Such statements are based on our current expectations and certain assumptions, and are, therefore, subject to certain risks and uncertainties. A variety of factors, many of which are beyond Siemens’ control, affect its operations, performance, business strategy and results and could cause the actual results, performance or achievements of Siemens worldwide to be materially different from any future results, performance or achievements that may be expressed or implied by such forward-looking statements. For us, particular uncertainties arise, among others, from changes in general economic and business conditions, changes in currency exchange rates and interest rates, introduction of competing products or technologies by other companies, lack of acceptance of new products or services by customers targeted by Siemens worldwide, changes in business strategy and various other factors. More detailed information about certain of these factors is contained in Siemens’ filings with the SEC, which are available on the Siemens website, www.siemens.com and on the SEC’s website, www.sec.gov. Should one or more of these risks or uncertainties materialize, or should underlying assumptions prove incorrect, actual results may vary materially from those described in the relevant forward-looking statement as anticipated, believed, estimated, expected, intended, planned or projected. Siemens does not intend or assume any obligation to update or revise these forward-looking statements in light of developments which differ from those anticipated.

Trademarks mentioned in this document are the property of Siemens AG, its affiliates or their respective owners.