An Overview

Center for Heat Treating Excellence

At Worcester Polytechnic Institute
Management Team

- Diran Apelian  Executive Director
- Richard Sisson  CHTE Director
- Mike Pershing  Chair, Board of Directors
- Roger Fabian  Director-at-Large
To be the premiere industry-university alliance serving the thermal processing industry by serving consortium members’ needs, by establishing the needed knowledge base, and by educating future leaders of the industry.
Industry-University Alliance in Action
Our Industrial Partners and Sponsors

Air Liquide • Air Products • ALD Vacuum Technologies • ASM Heat Treating Society • Bluewater Thermal Solutions • Caterpillar • Chrysler • Cummins Fuel Systems • John Deere • Harley-Davidson Motor Company • Houghton • Pratt & Whitney – Sikorsky • Praxair • Scientific Forming Technologies Corporation • Seco/Warwick • The Sousa Corporation • Spirol • Surface Combustion • Thermatool • The Timken Company
BUT...

Context / Applications are well defined

BY WHOM?

The Marketplace – the Industry
Research Programs

- **Pre-Competitive** Fundamental Research funded by the members

- **Large-Scale** Projects funded by the Federal Government or foundations leveraging the research agenda of the centers

- **Specific and Proprietary Research** conducted for collaborative members
Commercialization of Ideas
Innovation
Competitiveness of Our Industrial Members
“Theory and Practice”.......Practiced!!

“In theory, there is no difference between theory and practice. In practice, there is.”

Yogi Berra
Inter-disciplinary Approach

- Materials Engineering
- Mechanical Engineering
- Electrical Engineering
- Chemical Engineering
- Management/Marketing
- Other Universities
- Government Laboratories
CHTE Portfolio
Heat Treatment Processes

1. heating
   - Room temperature

2. Solutionizing/Austenization or Surface treating
   - $t = t_2$ hr

3. Quenching

4. heating
   - $t = t_5$ hr

5. Aging/Tempering
Alloy specific Lehrer diagrams developed for the first time and verified experimentally

Alloy specific isopleths - phase diagrams developed

Kinetic model framework developed using the Lehrer diagrams and isopleths – software to be ready for testing in the fall 2011

NitrideTool ©

Need experimental verification – testing at CAT

CHTE member testing

Model completion 6/2012
Isopleth vs. Nitrogen Concentration Profile
**Diffusion Coefficients**

- Inverse method used to fit the OES results
  \[ D^d = 9 \times 10^{-7} \text{cm}^2/\text{s}, \text{close to} 7.3 \times 10^{-7} \text{cm}^2/\text{s} \text{ (diffusivity of N in } \alpha) \] [1]
- Should be determined experimentally

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CarbTool© has been modified for carbon and nitrogen absorption – **CarboNitrideTool ©**

- Database needs for diffusivities of N and C
- Database needs for mass transfer coefficients and fluxes

- Experimental verification ongoing
- Simulation ready for testing in January 2013
- Model completion 12/2011
Carbon potential
- The initial $C_p$ without NH3 addition.

Carburizing time
- The time that only carburizing is operated.

Cp variation with NH3 addition
- When NH3 is added into the furnace, $C_p$ may be affected and drop a little which must be taken into account.

Process temperature

Nitrogen flux.
- Nitrogen flux as a constant or a function of time calculated by weight gain method.

Nitriding time
- The time with NH3 addition.
AISI 1018 850°C

Simulation Results
Simulation Results

8620 5% NH3 15min 850°C

\[ y = 1821.2x^3 - 32.129x^2 - 12.675x + 0.6884 \]

\[ R^2 = 0.99902 \]

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>c%</th>
<th>N%</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00E-03</td>
<td>7.22E-01</td>
<td>4.95E-02</td>
<td>6.88E+02</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

...
Continuing to work with Surface Combustion and SECO/WARWICK to develop recipes (process parameters) and carburize the steels.

Demonstrated the capability of matching the Carbon Concentration profiles for gas and vacuum carburizing

Project continuing – modeling with DEFORM for quenching effects
  - Residue Stress, retained Austenite, microstructure
\[ J(x) = \frac{d}{dt} \int_{C_0}^{C} x dC \]

\[ J = \text{Area under the curve} \times \text{Density} \times \frac{1}{\text{total effective carburizing time}} \left[ \frac{g}{cm^2s} \right] \]
**Comparison of Two Processes**

### Surface Carbon (wt.%)

<table>
<thead>
<tr>
<th>Process</th>
<th>9310</th>
<th>4320</th>
<th>8620</th>
<th>5120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>0.7±0.05</td>
<td>0.8±0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>0.63</td>
<td>0.65</td>
<td>0.80</td>
<td>0.82</td>
</tr>
<tr>
<td>Vacuum</td>
<td>0.58</td>
<td>0.58</td>
<td>0.70</td>
<td>0.77</td>
</tr>
</tbody>
</table>

### Effective Case Depth (mm)

<table>
<thead>
<tr>
<th>Process</th>
<th>9310</th>
<th>4320</th>
<th>8620</th>
<th>5120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>0.89±0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>0.67</td>
<td>0.87</td>
<td>0.82</td>
<td>0.84</td>
</tr>
<tr>
<td>Vacuum</td>
<td>0.71</td>
<td>0.78</td>
<td>0.80</td>
<td>0.80</td>
</tr>
</tbody>
</table>
Nondestructive Testing for Hardness and Case Depth Measurements

- Project planning completed
  - Design and fabrication of standard test samples will be the key to a successful project
- Literature review ongoing
- Standard Test Sample Design
  - DEFORM
  - Microstructure & Residual Stress
- Equipment identified
  - MWM and Barkhausen Noise Equipment secured!
- Preliminary Testing in Spring semester
- Estimated Completion 6/2013
Review of NDT Technologies

- Eddy current
- MWM
- Barkhausen noise
- Ultrasonic
- ACPD

Electro magnetic properties
- Only conductive materials can be inspected
- Depth of penetration is limited
- Surface finish and roughness may interfere

Hardness (case depth)

Microstructure

Stress
 Thermomechanical Processing of Light Alloys by Design

◆ Faculty: Rick Sisson, Diran Apelian, Makhlouf Makhlouf, Jianyu Liang, Nikolaos Gatsonis

**Cold Spray Process**

- **Powder Feeder**
- **Convergent-divergent nozzle**
- **Gas Heater**
- **Substrate**

Cu coating sprayed on an Al substrate

Tobias, S., & et.al. (2009). From Particle Acceleration to Impact and Bonding in Cold Spraying. *Journal of Thermal Spray Technology*
Research Objectives

Improve Properties of Cold Sprayed Al Alloys

For use in structural materials and armor

- Increase Toughness
  - Add alloying elements
  - Precipitation harden

- Increase Ductility
  - Remove grain boundary precipitates
  - Remove Fe

Thermodynamic & Kinetic Modeling
Alloying Element: Sc

At 0.05 wt% Sc

- Mg₂Si
- Al₁₃Fe₄
- Al₁₅(Fe,Mn)₃Si₂
- A1fcc
- Al₃Sc

Al₁₁Cr₂
- Mg₂Si
- T₁, T₂
- AlMg-β
- Al₃Ti
- A1fcc
- Al₁₃Fe₄
- Al₆FeMn
- Al₃Sc

Al₃Sc forms strong solid solution and does not cause much embrittlement
Currently testing TC-PRISMA with ThermoCalc for precipitation kinetics predictions

- TC-PRISMA is a new software package which can treat concurrent nucleation, growth and coarsening under isothermal conditions in multi-component and multi-phase systems by using Langer-Schwartz theory and Kampmann-Wagner numerical approach. Jointly developed by Thermo-Calc Software AB and QuesTek Innovations LLC, the software extends the functionality currently available through Thermo-Calc and DICTRA.
Intellectual Capital

- Collaborative members guide and select research projects
- Proprietary property developed is available to member companies (royalty free)
- Member-driven research programs on diverse and practical projects

Human Capital

- Access to faculty, students, industrial interns, and future employees
- Educate young adults for future careers and leadership positions
- Provides human capital and intellect for the 21st Century
- Industrial Internships
Benefits and Membership

- **Valuable Source of R & D Data**
  - Asset to the Metals Industry for more than twenty years
  - Research Project Reports – two reports per year
  - Participation and discussion through focus groups and steering committees at two annual meetings (June and December)
  - Cost Effective – Facilities and human capital are shared by other MPI centers
Meetings

- Two Annual Meetings – typically, June and December
- Workshops and Seminars on topical themes

Cost

- Annual Dues: $25,000 per membership year (flexible payment options available)

How to Join

- Email Prof. Diran Apelian – dapelian@wpi.edu
- See Website: http://www.wpi.edu/academics/Research/MPI/
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