Stainless Steel Architectural Design

Sponsors:
Nickel Institute
Indian Stainless Steel Development Association

Speaker: Catherine Houska
Why Should You Consider Stainless Steel?

• Sustainable
  – Longevity, energy savings, no VOCs
• Attractive & provides design flexibility
  – Wide range of finishes on sheet and strip
  – Any metal design is possible
• Structural benefits include
  – Enhances safety & security
  – High strength
  – Reduces section sizes
  – Seismic performance

1 World Trade Center
Type 316 Linen & spire
Gold LEED expected
World Green Building Council
Countries & Associated Groups

A rapidly growing international mega trend

WGBC founded by 9 countries in 2002

Now 97 countries and affiliated groups
Defining Sustainability

- Voluntary scoring systems
  - Most widely used
    - LEED, Green Star, BREEAM
    - Development of global versions
      - India GBC LEED and Green SEZ
  - International specifications and guides
    - ISO, ASHREA, ASTM E60, ENs, etc.
    - Defining sustainable manufacturing, business and construction
      - Example: ASTM E60 standard on sustainable dentistry
Environmental & Economic Benefits

• Energy & water reduction provide both economic and environmental benefits
• US statistics for buildings
  – 36% energy use
  – 30% of greenhouse gas emissions
  – 12% of potable water consumption
  – 30% raw material production
  – International averages are higher (>40% greenhouse gases)

Empire State Building, 1931, LEED Gold
Stainless spandrel panels, window frames and spire
Why is Stainless Steel Sustainable?

• Stainless steel’s inherent characteristics
  – Long service life
  – Can be restored & reused during renovation
  – Diverted from landfills
    • Indefinitely recyclable into the same high quality product
  – High scrap content
  – No emissions unless you coat it
  – Helps to reduce energy requirements
  – No toxic run off
• Specific products have additional benefits

525 William Penn Place, Pittsburgh, Pennsylvania Completed in 1952, 2002 renovation – Original SS
## Average Rates (%)

<table>
<thead>
<tr>
<th>Material</th>
<th>Recycled Content</th>
<th>Recapture Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheet/strip</td>
<td>25-35 **</td>
<td>70</td>
</tr>
<tr>
<td>Structural</td>
<td>≤95 **</td>
<td>97</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>70 - 90**</td>
<td>92*</td>
</tr>
<tr>
<td>Zinc</td>
<td>23 **</td>
<td>33</td>
</tr>
<tr>
<td>Copper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical wire</td>
<td>0 *</td>
<td>&gt;90</td>
</tr>
<tr>
<td>Other products</td>
<td>70 – 95 *</td>
<td>&gt;90</td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheet</td>
<td>0 *</td>
<td>70</td>
</tr>
<tr>
<td>Extrusions</td>
<td>Varies *</td>
<td>70</td>
</tr>
<tr>
<td>Castings</td>
<td>≤100 *</td>
<td>70</td>
</tr>
</tbody>
</table>

* ABC Industry  ** All Applications
Stainless Steel Provides Long Life

Chrysler 1930

Savoy Hotel Canopy 1929

Shakaden Temple 1975

Empire State 1931

Thyssenhaus 1956

Gateway Arch, 1965
Important Trends

- Whole Building Life Cycle Assessment
  - Minimum project life requirements
    - ASTM E60 is using 75 years
    - LEED & BREEAM = 60 years min.
  - Material environmental impact x # replacements
- Population growth/redevelopment
  - High pollution areas & coastal areas
- Increased & more aggressive deicing salt

US Federal Courthouse
Eugene, Oregon, USA
US Gold LEED, 100 year life

Doha Convention Center
2205 Tower & Convention Center base
Other Metals Have Shorter Service Life & Require More Maintenance

- Peeling painted carbon steel
- Peeling painted aluminum roof, 25 years
- Peeling painted aluminum, Florida, <10 yrs
Reducing Energy Use & Heat Islands

- Material and finish choice affects energy performance
- Solar Reflective Index (SRI)
  - Calculated based on ASTM E1980
  - Solar Reflectance & Emittance
    - Varies with material & finish
    - Roof slope (1:6) & exterior walls ≥ 39
    - Low slope roofs ≥ 82
- In 3 years, SRI values can not deteriorate below 32 and 64
  - Unlike other materials, stainless steel SRI values do not decrease over time

Pittsburgh Convention Center (2003)
- Was Gold LEED after construction
- Now LEED Platinum Existing Building
- 2/3% less water, 29% less energy
- 50+ year life requirement
<table>
<thead>
<tr>
<th>Product</th>
<th>Temperature Rise, at C (F)</th>
<th>Solar Reflective Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel, bare</td>
<td>27 (48 F)</td>
<td>39-60</td>
</tr>
<tr>
<td>Galvanized steel, new bare</td>
<td>30 (55 F)</td>
<td>46</td>
</tr>
<tr>
<td>Aluminum, new bare</td>
<td>27 (48 F)</td>
<td>56</td>
</tr>
<tr>
<td>Any metal, white coating</td>
<td>9 (16 F)</td>
<td>107</td>
</tr>
<tr>
<td>Clay tile, red</td>
<td>32 (58 F)</td>
<td>36</td>
</tr>
<tr>
<td>Concrete tile, red</td>
<td>39 (71 F)</td>
<td>17</td>
</tr>
<tr>
<td>Concrete, white dirty</td>
<td>37 (67 F)</td>
<td>22</td>
</tr>
<tr>
<td>Concrete, new white</td>
<td>12 (21 F)</td>
<td>90</td>
</tr>
<tr>
<td>Asphalt, generic white</td>
<td>36 (64 F)</td>
<td>26</td>
</tr>
<tr>
<td>Asphalt, generic black</td>
<td>46 (82 F)</td>
<td>1</td>
</tr>
<tr>
<td>Wood shingle, brown</td>
<td>37 (67 F)</td>
<td>22</td>
</tr>
<tr>
<td>Wood shingle, white</td>
<td>6 (10 F)</td>
<td>106</td>
</tr>
</tbody>
</table>

Sources: LBNL Cool Roofing Materials Database and finish producers
Welded Stainless Green Roof Liners

1. Plants in soil
2. Filter membrane
3. Drainage layer
4. Welded molybdenum-containing stainless steel
5. Thermal insulation
6. Vapor barrier
7. Roof deck
Paul Klee Center, Berne

- Renzo Piano Building Workshop
- Undulating shape mimics the hills
- Type 316 roof trays are used to create vegetated roof
Important Trends

- Building energy modeling software
  - US DOE free COMFEN software
    - Large number of buildings analyzed
    - For different design variables calculates energy use/cost, CO$_2$
- Exterior sunscreen impact
  - Uses sunscreen solar reflectance & transmittance
  - More relevant than % of open area
  - Sheltered locations are more corrosive application = stainless steel
- Solar Reflective Index of exterior materials
  - Stainless SRI can not deteriorate over time

San Francisco Federal Building
Type 316 perforated sunscreens
Surpasses the U.S. government energy performance criteria by 50%
COMFEN Building Example
Eastern Michigan University, USA

- Woven mesh sunscreens, 35% open area
- US Department of Energy free COMFEN software predicted energy reduction
- Northern climate, air temperature 24 C
  - Building exterior temperature
    - 34.4 C no shading
    - 27.8 C with shading
Compared 3 Different facades
1. No Metal Fabric
2. With Metal Fabric (50% open area)
3. With Metal Fabric (35% open area)
Comfen Computed the annual energy required to heat and cool the buildings based on the different façade configurations.
% diff. from Base Case compares the total energy savings 35% open area (30.45%) or 50% open area (24.20%) GKD Metal fabric would save versus using no fabric at all.
Recent Stainless Sunscreen Examples

Guangzhou China
2nd Children’s Activity Center
Woven mesh

Cooper Union, NYC
Perforated screens, LEED Platinum
40% energy savings
September 11 Museum Building, New York

- Situated between the sites of the two towers
  - Perforated Type 316 roof and wall sunscreen cladding
  - Two finishes to create texture
    - Glass bead blasted and mirror polished
- Other park applications
  - Type 316 park benches, water feature components, lighting, subway station canopy
  - 2205 walkway gratings
Stainless Steel Green (Plant) Sun Screens
Council House 2, Australia, Green Star 6
Just Announced KPF – New Exterior
Petersen Automotive Museum, Los Angeles

Ribbons of vibration polished stainless steel will wrap the existing building in light
Sun Screens

Installation of perforated sunscreens over an existing glass wall dramatically reduced heat gain.
# Metal Roof Run-Off Averages (mg/m²)

<table>
<thead>
<tr>
<th>Material</th>
<th>Copper</th>
<th>Lead</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rusty galvanized</td>
<td>20</td>
<td>302</td>
<td>12,200</td>
</tr>
<tr>
<td>Asphalt</td>
<td>11</td>
<td>10</td>
<td>1,980</td>
</tr>
<tr>
<td>Galvanized iron</td>
<td>ND</td>
<td>100</td>
<td>3,600</td>
</tr>
<tr>
<td>Concrete tile</td>
<td>ND</td>
<td>90</td>
<td>1,600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Nickel</th>
<th>Chromium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 304 Stainless*</td>
<td>0.3 - 0.4</td>
<td>0.25 - 0.3</td>
</tr>
</tbody>
</table>

*In many samples, nickel and chromium levels were below detectable limits. The average concentration per liter was well below typical drinking water levels.
Stadium Australia

Type 316, 2B finish

Drainage system collects water in underground tanks for watering grass and flushing toilets

Stainless is also used for in-building water treatment plants
Scottish Parliament

• Many common building materials release emissions
  – Reducing these creates a healthier environment
  – Bare uncoated metal has no emissions

• Stainless, wood and concrete
  – Interior stainless structural supports, wall and ceiling panels
How Does A Stainless Steel Work?

Stainless steel is iron + at least 10.5% chromium

Rust

Carbon Steel

< 10.5% Chromium

Passive Film

Stainless Steel

≥ 10.5% Chromium
Families of Stainless Steels

- **Austenitic**
  - 300-series numbers (304, 316)
  - Strengthened by cold work, easy to form, bend & weld
  - Nonmagnetic

- **Ferritic**
  - 400-series (430, 447)
  - Magnetic
  - Least formable

- **Duplex**
  - Austenitic/ferritic (2304, 2205)
  - Cost effective
    - Corrosion resistance
  - Higher strength
  - Magnetic
Select Type 304

- Rural/suburban
- Low to moderate pollution

Select Type 316

- Pollution
  - Moderate to high urban
  - Low to moderate industrial
- Coastal and deicing salt
  - Low to moderate exposure

Higher Alloys Like 2205

- High pollution or salt exposure
- High particulate
- No rain washing
More Corrosive Locations

Stockholm Congress Ctr
2205 Sunscreen

2205 Railings, Canary Island 30 years
Some Architectural Stainless Steels
(Nominal Chemical Composition, Wt. Pct.)

<table>
<thead>
<tr>
<th></th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>N</th>
<th>PREn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferritic 430</td>
<td>17</td>
<td>---</td>
<td>---</td>
<td>0.03</td>
<td>17</td>
</tr>
<tr>
<td>Austenitic 304</td>
<td>18</td>
<td>9</td>
<td>---</td>
<td>0.06</td>
<td>20</td>
</tr>
<tr>
<td>Ferritic 444</td>
<td>17.5</td>
<td>---</td>
<td>1.75</td>
<td>---</td>
<td>23</td>
</tr>
<tr>
<td>Duplex 2304</td>
<td>21.5</td>
<td>3</td>
<td>0.5</td>
<td>0.05</td>
<td>22</td>
</tr>
<tr>
<td>Austenitic 316</td>
<td>17</td>
<td>11</td>
<td>2</td>
<td>0.06</td>
<td>23</td>
</tr>
<tr>
<td>Austenitic 317LMN</td>
<td>17</td>
<td>13.5</td>
<td>4</td>
<td>0.10</td>
<td>32</td>
</tr>
<tr>
<td>Duplex 2205</td>
<td>22</td>
<td>5</td>
<td>3</td>
<td>0.15</td>
<td>34</td>
</tr>
<tr>
<td>Super duplex</td>
<td>24</td>
<td>6</td>
<td>3</td>
<td>0.24</td>
<td>38</td>
</tr>
<tr>
<td>Austenitic 6% Mo</td>
<td>19.5</td>
<td>17.5</td>
<td>6</td>
<td>0.18</td>
<td>41-43</td>
</tr>
</tbody>
</table>

PREn (Pitting Resistance Equivalent number) = %Cr + 3.3(%Mo) + 16(%N)
Provides a comparison of relative corrosion resistance that is helpful for many but not all service environments
What Factors Influence Corrosion?

- Pollution
  - Acid rain
  - Sulfur Dioxide & particulate
- Particulate accumulation (pollution or dust)
- Coastal and deicing salt exposure
- Weather conditions
- Maintenance cleaning
- Design/specification
  - Crevices
  - Sheltered locations (more corrosive)
  - Surface finish roughness & application method
- Handling & post fabrication cleaning
Coastal Salt Exposure
US Coastal Salt Map
Deicing Salt (Chloride) Corrosion

- Multi-year study
  - IL DOT, NADP, Argonne National Lab
- High seasonal accumulation
- Large saltwater droplets
  - Splash zone (≤ 49 ft.)
- Dry particles
  - ≤ 1.2 miles from roads
  - ≤ 59 floors
  - Stays in the air for days

Deicing salt corrosion in Beijing
New Corrosion Corrosion Map for India
Dubai Beach Site Corrosion Rates Predict Perforation - Standing Seam Roof Example

<table>
<thead>
<tr>
<th>Metal</th>
<th>Corrosion Rate Dubai Coastal Inch/year</th>
<th>SMACNA Thickness Inch</th>
<th>Time To Perforation, Yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2205 Duplex*</td>
<td>0</td>
<td>0.015</td>
<td>50+</td>
</tr>
<tr>
<td>Galvanized steel**</td>
<td>0.02</td>
<td>0.024</td>
<td>2.2</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.002</td>
<td>0.032</td>
<td>16</td>
</tr>
<tr>
<td>Zinc***</td>
<td>0.035</td>
<td>0.028</td>
<td>Less than 1</td>
</tr>
<tr>
<td>Copper</td>
<td>0.004</td>
<td>0.022</td>
<td>5.5</td>
</tr>
</tbody>
</table>

* Type 304/316 guidance was used. Lighter gage maybe possible.
** A G140 coating (0.001 inch) was assumed to have delayed carbon steel corrosion by 1 year based on zinc corrosion rates, this may not be accurate.
*** Zinc thickness for a double rolled standing seam per Rheinzink Applications in Architecture
Near Dubai Site
King Abdulaziz Center for World Culture
Duplex 2205 Stainless Steel Selected

• Corrosion testing documented severity of location
• Paint would have failed & not been repairable
• Less highly alloyed stainless steels would have had a corrosion problem
• High strength allowed lighter tube wall
Surface Finish
Is As Critical As Stainless Steel Selection

Increasing Corrosion Rate

Surface Roughness, $R_a$ microns

$R_a$ 0.5 microns or 20 micro-inches
Light Corrosion Staining Or Abrasion Can Destroy Some Finishes

- Corrosion or abrasion of colored stainless is not repairable
  - Cleaning leaves bare stainless steel – silver spots
Galvanic Corrosion Requires...

- Dissimilar metals
- Electrical connection between metals (i.e., metal-to-metal contact)
- Moisture is present and connects the metals on a regular basis

Solution

- Prevent direct contact
  - Inert washers
  - Paint
  - Other non-conducting barriers

Surface area ratio is important!

Stainless steel plate/galvanized steel fasteners
St Mary’s Cathedral, Tokyo,
Completed 1961, Type 304, 2D, near coast

- No problems with the stainless steel
  Galvanic corrosion of carbon steel framing made repairs necessary
Obtaining a Uniform Appearance

- Use one coil or consecutive coils from one supplier
- Mark rolling direction and number panels
- Install all panels in the same rolling direction
- Install numbered panels consecutively
- Failing to follow these rules produces a checkerboard appearance
<table>
<thead>
<tr>
<th>Metal</th>
<th>Thermal Expansion $^\circ$C x $10^{-6}$</th>
<th>Thermal Conductivity (W/m-C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 304/316</td>
<td>16.9</td>
<td>0.16</td>
</tr>
<tr>
<td>2205</td>
<td>13</td>
<td>0.23</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>12</td>
<td>0.54</td>
</tr>
<tr>
<td>Alloy 400</td>
<td>13.9</td>
<td>0.26</td>
</tr>
<tr>
<td>Copper</td>
<td>16.9</td>
<td>3.86</td>
</tr>
<tr>
<td>AA 3003</td>
<td>23.2</td>
<td>2.04</td>
</tr>
</tbody>
</table>
Flat Unlaminated Panels

Dull or coined finishes look flatter than more reflective finishes and thinner gauges can be used.

<table>
<thead>
<tr>
<th>Reflectivity</th>
<th>Width-to-Thickness Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>150 max.</td>
</tr>
<tr>
<td>Medium-to-low</td>
<td>200 max.</td>
</tr>
<tr>
<td>Coined/Embossed</td>
<td>200 or higher</td>
</tr>
</tbody>
</table>
No. 4 Polish
• Short parallel lines

Hairline
• Long fine parallel lines

No. 8 Polish
• Mirror like

Neuer Zollhofs, Dusseldorf, Germany, Gehry Partners
Acid Etching

- Unprotected areas are etched to create the design
- The acid is rinsed off and the coating is removed
- Etched areas are a dull silver color
- Custom and stock patterns available
- Etched areas can have fingerprinting problems
Vibration Finish
(angel hair, suede, non-directional polish)

- Stainless wire brush or non-metallic abrasive pad
- Applied to a mirror polished or bright annealed finish
- Non-directional, fine, random scratch pattern
- Lines are smaller, finer than distressed finish
- Use control samples

Walt Disney Concert Hall, Gehry Partners
Swirl Finishes

• Applied over 2B or 2D finish
• Grinding wheels or stainless wire brushes
• Swirl patterns
• Use control samples
Effect of Abrasive Blast Media

- Non-directional and repairable
- Surface distortion if panels are too thin
- Susceptible to fingerprinting
- Clean surface before and after blasting

<table>
<thead>
<tr>
<th>Media</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine sand</td>
<td>Dark, coarse</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>Dark, coarse</td>
</tr>
<tr>
<td>Glass beads</td>
<td>Light, smooth, grainy</td>
</tr>
<tr>
<td>Stainless shot</td>
<td>Small, curved indentations</td>
</tr>
<tr>
<td>Ground quartz</td>
<td>Shiny, coarse, angular indentations</td>
</tr>
</tbody>
</table>
Liner Museum
Appenzell, Switzerland

3 mm thick, glass bead blasted stainless shingles roof and wall panels
Embossing and Coining

• Applied by passing a stainless steel coil between two rolls
• Improves scratch and impact resistance
• Coining
  – One roll is patterned
  – One roll is smooth
• Embossing
  – Both rolls are patterned
Electrochemical Colors

Similar to anodizing aluminum
Color can be uniform or deliberately varied

Bronze        Blue        Gold        Red
Purple        Black       Green
Sputtering or Plasma Vapor Deposition

- Thin, adherent, abrasion resistant, uniform, non-fading
- Color determined by coating
  - Gold (titanium nitride)
  - Black (titanium carbide)
  - Brown or Blue (titanium aluminum nitride)
- Others: Rose Gold, Silver Gold, Brass
Perforated Panels

• Decorative, sunscreen, security and safety applications

US court house sunscreens, Type 316 Surpassed energy performance criteria by 50%
Woven Stainless

• Many styles and weights
• Hides scratches and impact resistant
• Interior and exterior applications
  • Ceilings, walls, room dividers
  • Sunscreens and sculptural shapes
• Salt crevice corrosion must be considered
Questions?

10 Minute Break Before Applications Discussion