Stainless Steel Architectural Design

Sponsors: Nickel Institute
ISSDA

Speaker: Catherine Houska

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Topics

- Sustainability
- Selection, design & maintenance
- Finish options
- Project Specification
- Interior & exterior applications
- Roofing
- Structural applications

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Why is Sustainable Design Important?

- Buildings consume
  - 40% of the world's energy
  - 32% of world's materials
  - 12% of our water
- India Green Building Council estimates
  - Domestic market for green building materials & equipment will exceed $50 B by 2012

Stainless Steel Provides Proven Longevity

- Numerous projects 80+ years of service
  - Excellent performance
- Appropriate specification & maintenance
  - Potentially 100's of years of service

Chrysler Building
1930
First large stainless roof

Gateway Arch, 1965
First large stainless structural application

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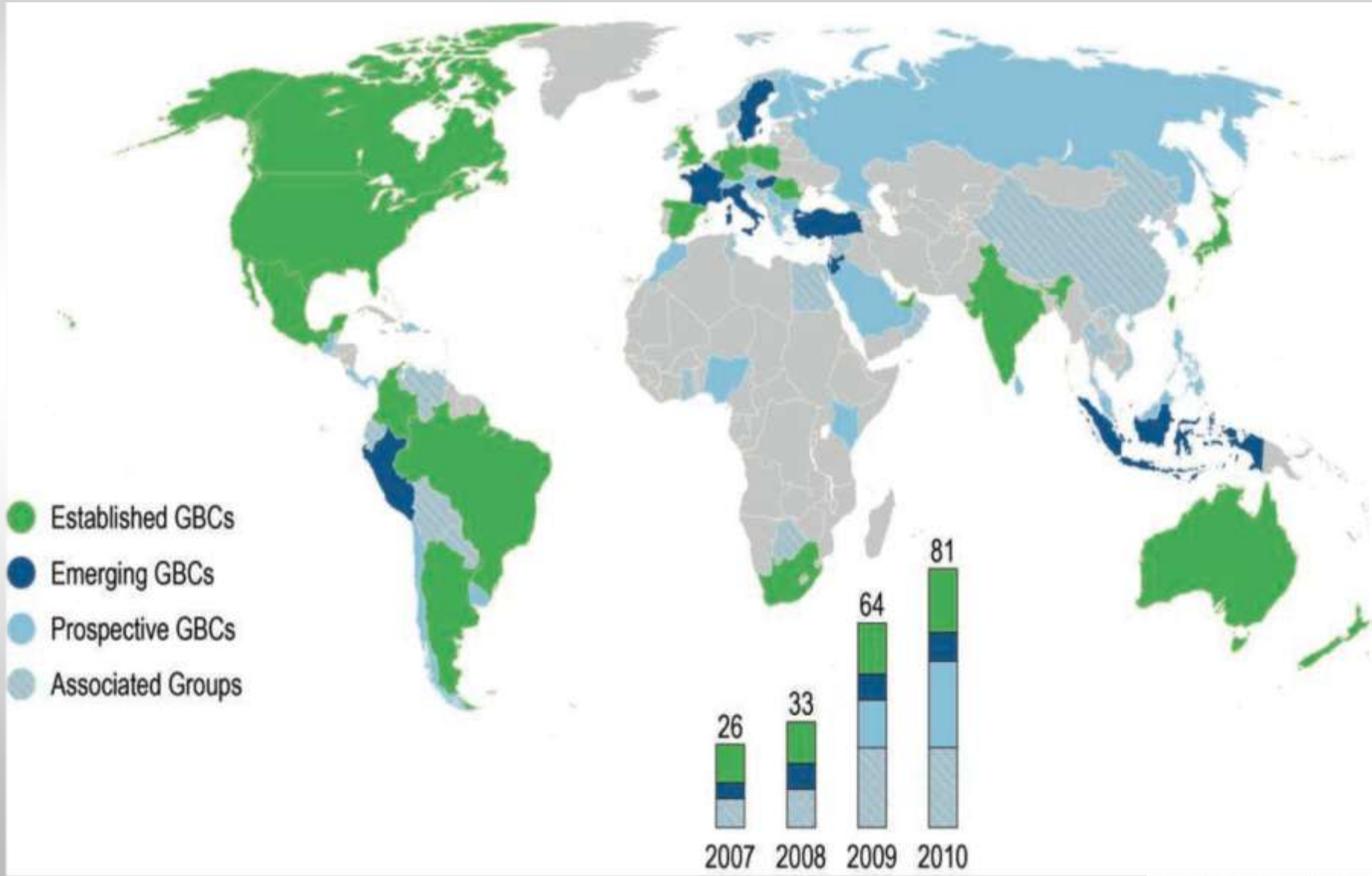
The Driving Force – World Green Building Council (WGBC) Countries

- Scoring systems for all types of building and construction projects
  - All building types, water treatment plants, infrastructure, industrial buildings
- LEED
  - Formally used in US, Canada, India
  - Dominant international scoring system
  - Internationalization of LEED
    - Input from 22 countries
    - Adaptable to local priorities

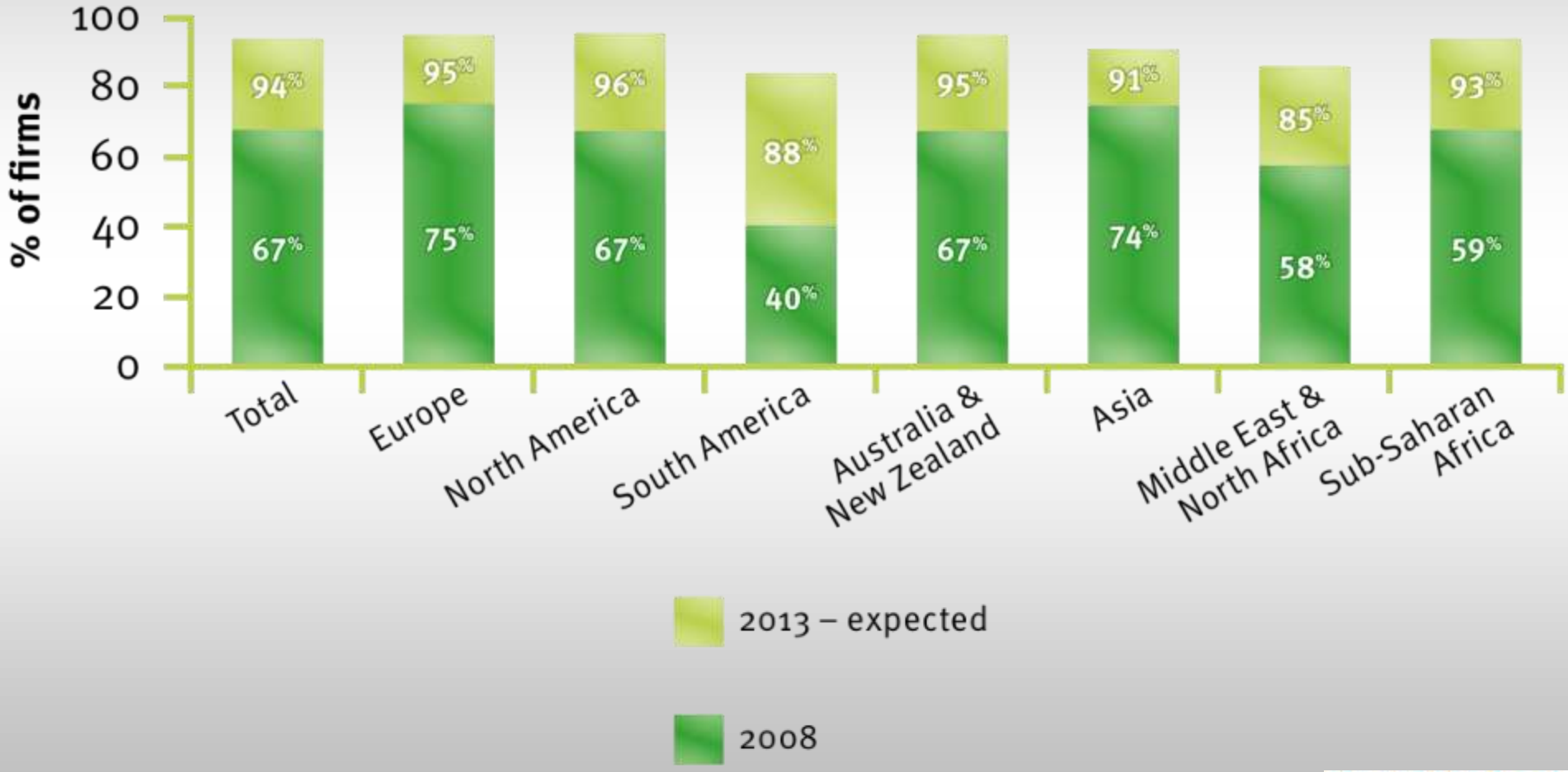
World Green Building Council Countries

92 countries with current/emerging scoring systems



International Corporate Commitment

% of firms dedicated to green building on at least 16% of projects, by region



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Sustainable Construction Characteristics

- Design for long service life
- Minimize material use, waste & impact
  - Avoid replacement during service life
  - High recycled content or renewable
  - No landfill waste or high recapture rate
- Preserve natural resources & building environment
  - Minimize energy and potable water use
  - Minimize toxic run-off and other environmental impacts
  - Capture and reuse gray water
- Healthy productive indoor environment
  - Low emission materials and natural light

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Life Cycle Cost

Two Piers, Progreso, Mexico

Long service life = no material replacement
Cost effective and environmentally friendly
Minimum service life mandated in countries with green building requirements

- Functional pier
  - About 70 years old (1937-1941)
  - Stainless rebar
- Non-functional pier
  - 30 years after construction
  - Carbon steel rebar

Photo courtesy of the Nickel Institute

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Average Rates (%)

	Recycled Content	Recapture Rate
Carbon Steel		
Sheet/strip	25-35 **	70
Structural	≤95 **	97
Stainless Steel	60 - 90**	92
Zinc	23 **	33
Copper		
Electrical wire	0 *	>90
Other products	70 – 95 *	>90
Aluminum		
Sheet	0 *	70
Extrusions	Varies *	70
Castings	≤100 *	70

* ABC Industry ** All Applications

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Reusing Stainless Steel

525 William Penn Place
Pittsburgh, Pennsylvania
Completed in 1952

- Stainless entrance/lobby
- Exterior spandrel panels
- Lobby renovation in 2002
- Most of the stainless steel was refinished and reused
- Architect IKM

Before

After

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Stainless Steel Can Be Easily Restored

Photo courtesy of Allegheny Ludlum

150 East 42nd Street, New York City
Cleaned for the first time after 40 years of service

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Jamaica Train Terminal, New York

100 year design life - with low maintenance

Type 316 - coastal, moderate urban pollution

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Wayne L Morse US Federal Courthouse Eugene Oregon, US Gold LEED 2006

Type 304, vibration finish

100 year design life

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Reducing Energy Use & Heat Islands

- Material and finish choice affects performance
  - Exterior roof & wall panel materials
  - Sunscreens
- Solar Reflective Index (SRI)
  - Calculated based on ASTM E1980
  - Solar Reflectance & Emittance
  - Varies with finish
- Roof slope (1:6) & exterior walls ≥ 29
- Low slope roofs ≥ 79

Perforated sunscreens
San Francisco Federal Building
Woven sunscreens Planet M, Hanover

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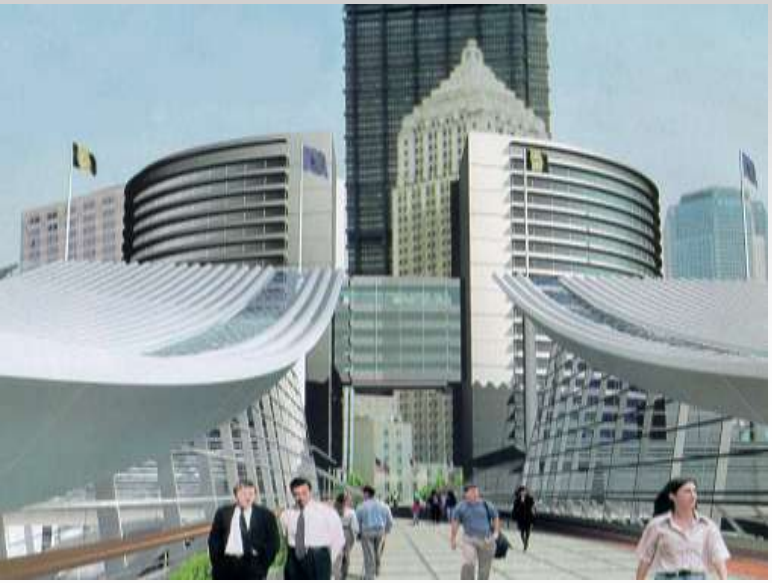
Product	Temperature Rise, at C (F)	Solar Reflective Index
Stainless Steel, bare	27 (48 F)	39-60
Galvanized steel, bare	30 (55 F)	46
Aluminum, bare	27 (48 F)	56
Any metal, white coating	9 (16 F)	107
Clay tile, red	32 (5 8F)	36
Concrete tile, red	39 (71 F)	17
Concrete tile, white	12 (21 F)	90
Asphalt, generic white	36 (64 F)	26
Asphalt, generic black	46 (82 F)	1
Wood shingle, brown	37 (67 F)	22
Wood shingle, white	6 (10 F)	106

Sources: LBNL Cool Roofing Materials Database and finish producers

Pittsburgh Convention Center (2003)
World's First Sustainable Convention Center



- Type 304
- Batten cap design
- High wind uplift resistance

- Heating/cooling by 33%
- High recycled content
- Locally produced
- 50+ year life requirement

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Guangzhou China
2nd Children's Activity Center

Type 316 woven mesh sun screens helped to eliminate air conditioning in public spaces

Curving sunscreens made a simple concrete building very modern at reduced cost

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US Federal Building, San Francisco

- Type 316 perforated sunscreens
- Surpasses the U.S. government energy performance criteria by 50%

University - Cooper Union New York

- Type 316 sunscreens contributed to 40% energy savings
- USGBC Platinum LEED rating

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Italian Engineering Building Renovation

Perforated stainless sunscreens
Reduce air conditioning requirements and provide low maintenance long service life

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Stockholm Congress Centre

2205 Sunscreens reduce energy requirements

Swedish Green building certification expected

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ThyssenKrupp AG Corporate Headquarters

- Type 316 sunscreens on multiple buildings
- Contributing to 20-30% energy savings
- Pre-certificate Gold German Certification for Sustainable Buildings

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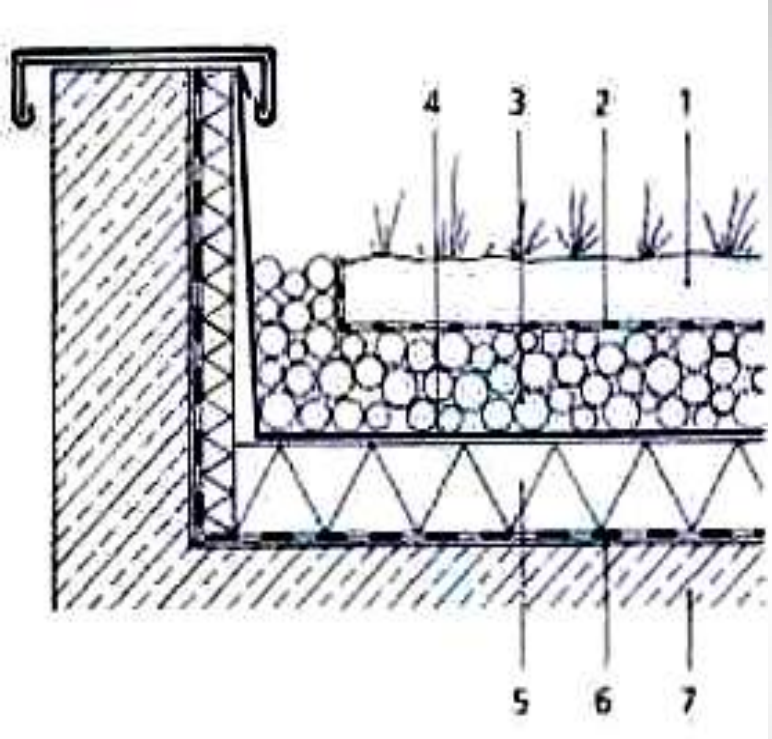
Welded Stainless Green Roof Liners



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

Metal Roof Run-Off Averages (mg/m^2)

	Copper	Lead	Zinc
Rusty galvanized	20	302	12,200
Asphalt	11	10	1,980
Galvanized iron	ND	100	3,600
Concrete tile	ND	90	1,600

	Nickel	Chromium
Type 304 Stainless*	0.3 - 0.4	0.25 - 0.3

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

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Stadium Australia

Type 316 , 2B finish

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

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

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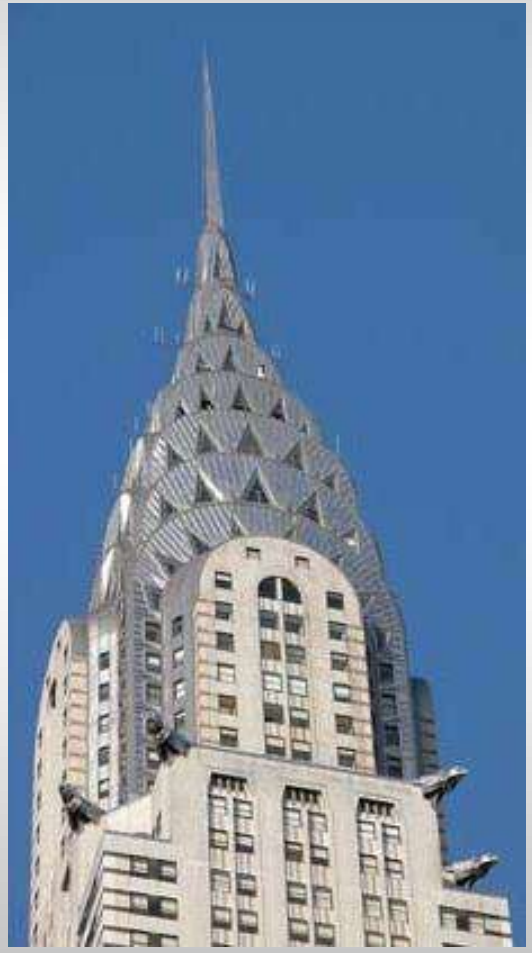
Stainless Steel
Ideal For Sustainable Construction

- Indefinitely recyclable
- High scrap content
  - not down-cycled
  - highly valued and recaptured
- Can reduce building energy and environmental costs
- Can help to save water
- Extents building life
- Can be restored and reused



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How Does A Stainless Steel Work?

Stainless steel is iron + at least 11% chromium

Rust

< 11% Chromium

Passive Film

> 11% Chromium

Major Alloying Elements

- Iron (Fe)
- Chromium (Cr)
  - Improves corrosion resistance
- Molybdenum (Mo)
  - Improves resistance to corrosion caused by salt (chlorides) and pollution
- Nickel (Ni)
  - Improves ductility, toughness, and weldability
- Nitrogen (N)
  - Improves strength and corrosion resistance

Families of Stainless Steels

- Austenitic
  - 300-series numbers (304, 316)
  - Strengthened by cold work
  - Nonmagnetic
- Ferritic
  - 400-series (430, 447)
  - Magnetic
- Duplex
  - Austenitic/ferritic (2205)
  - More corrosion resistant
  - Higher strength
  - Magnetic

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What Factors Influence Corrosion?

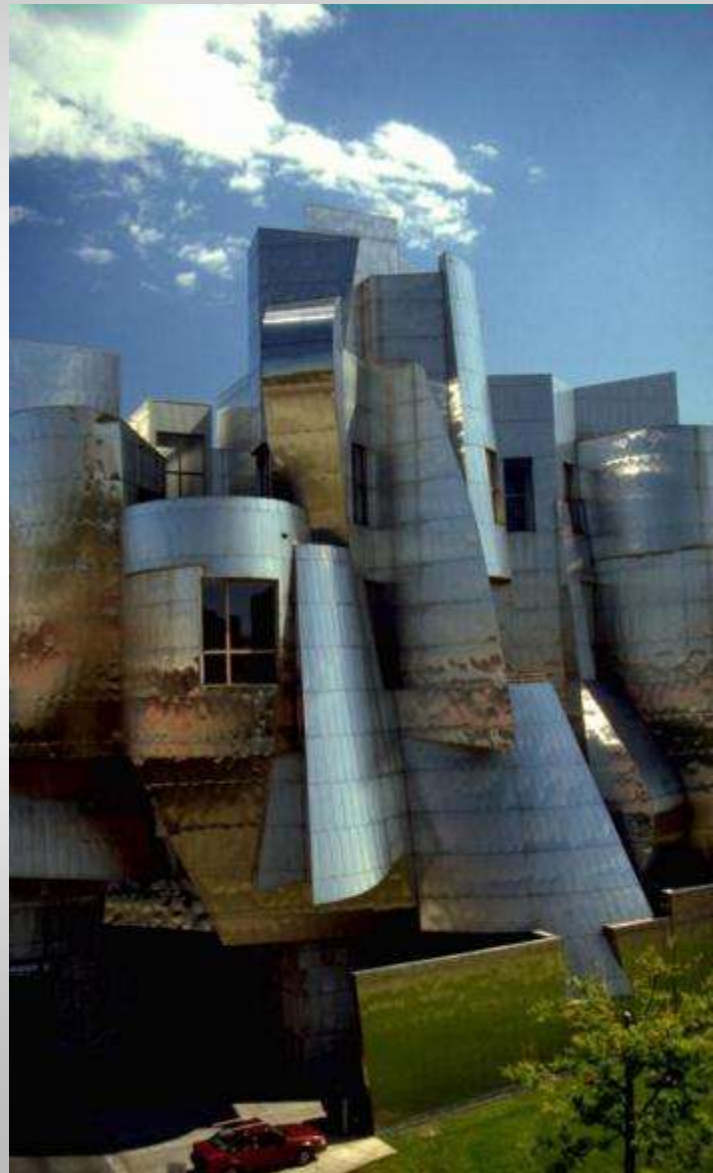
- Pollution
  - Acid rain
  - Sulfur Dioxide & particulate
- Coastal and deicing salt exposure
- Weather conditions
- Maintenance
- Design/specification
  - Crevices
  - Finish
- Surface finish roughness & application method
- Handling & post fabrication cleaning

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



Select More Corrosion Resistant Stainless Steels

- Industrial pollution
  - High sulfur dioxides levels
  - High particulate levels
- Coastal or deicing salt
  - Salt water splashing or immersion
  - Sheltered unwashed applications
  - Significant deicing salt deposits

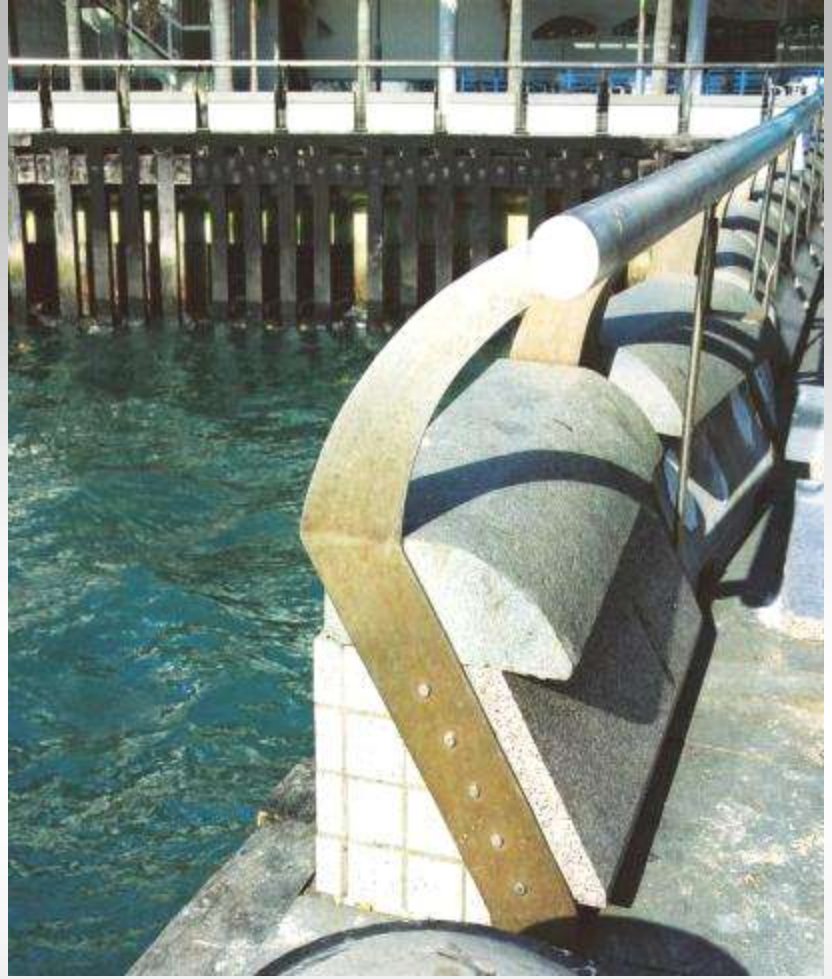


Photo courtesy of the Nickel Institute

Type 316 railings
Hong Kong Convention Center
seawater spray exposure
rough surface finish

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Architectural Stainless Steels

(Nominal Chemical Composition, Wt. Pct.)

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

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

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Rating Pollution Levels

City	Pollution Level	Suspended Particulate µgm/m^3	Sulfur Dioxide µgm/m^3
Rio de Janeiro	High	139	129
Beijing	High	377	90
Calcutta	High	375	49
Moscow	High	100	109
Tokyo	Moderate	49	18
New York	Moderate	27	26
Chicago	Moderate	35	14
Stockholm	Low	9	5
Paris	Low	14	14

World Health Organization Data

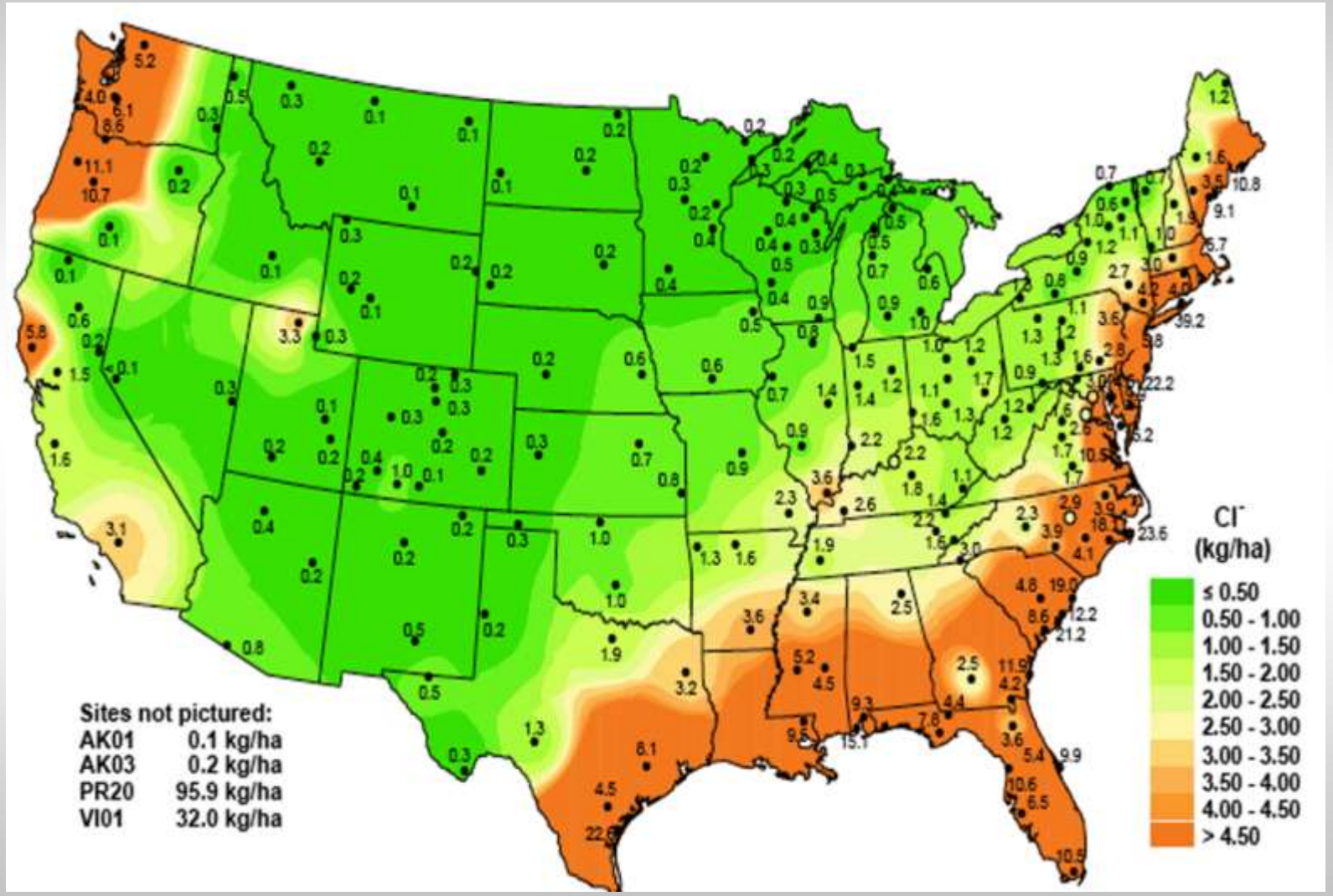
Rain Acidity (pH)

Critical Temperature/Humidity Combinations for Salt (Chloride) Corrosion

Critical	Critical Humidity Level, %		
Temperature °C (°F)	Sodium Chloride	Calcium Chloride	Magnesium Chloride
25 (77)	76	30	50
10 (50)	76	41	50
0 (32)	---	45	50

Coastal Salt Exposure

US Coastal Salt Map



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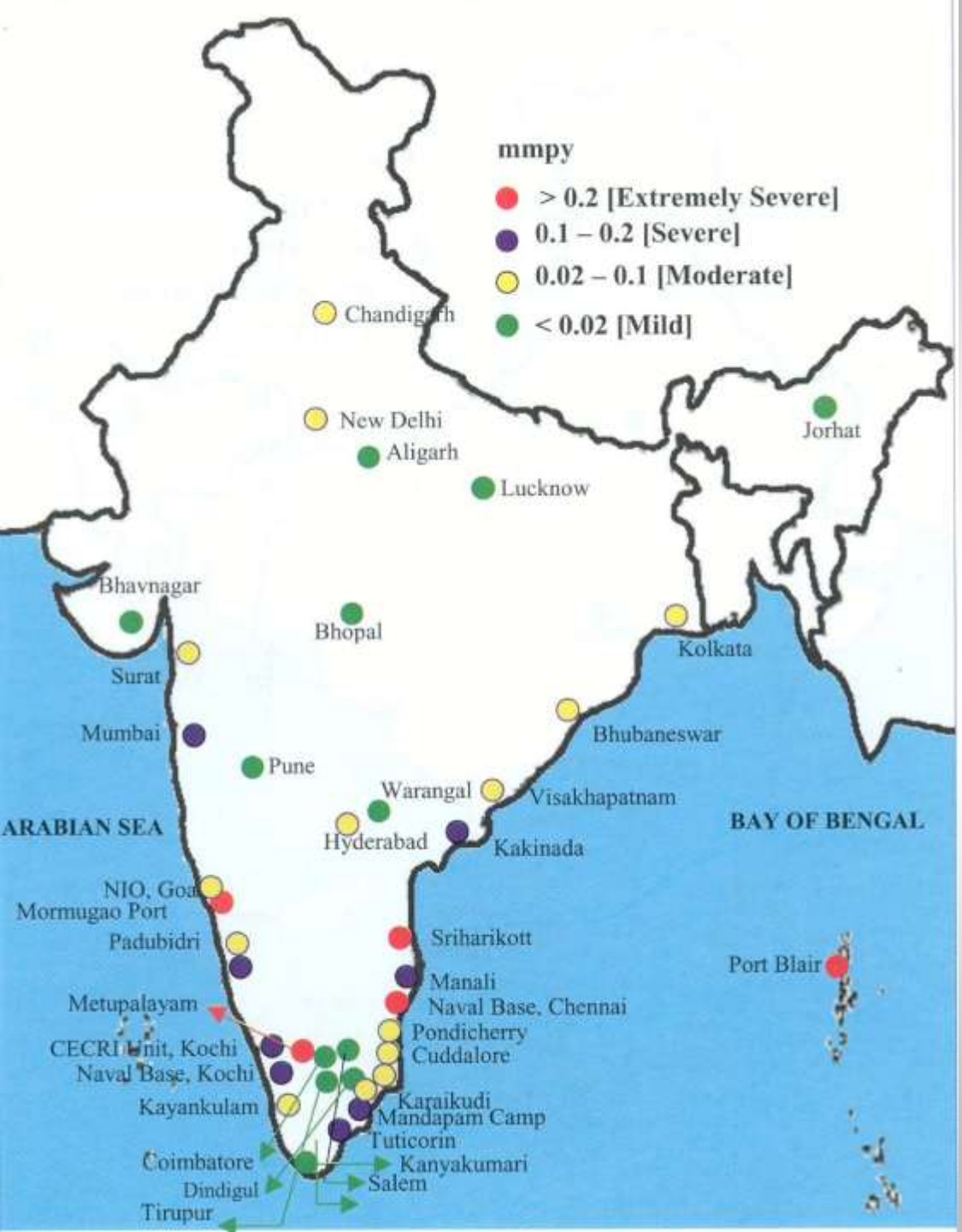
New Corrosion Map for India



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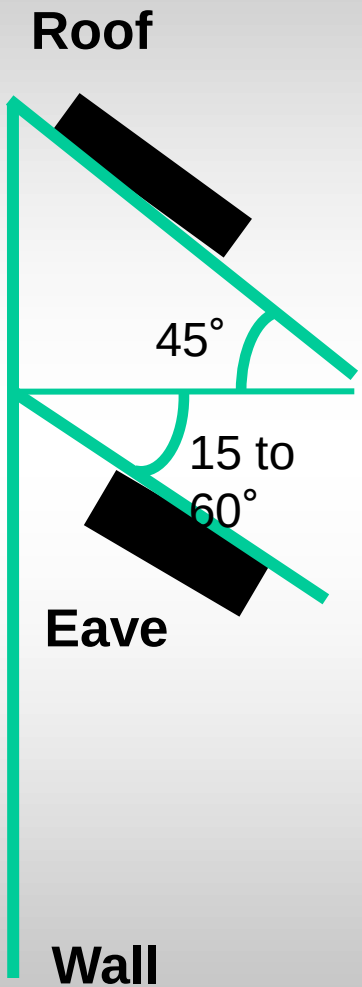
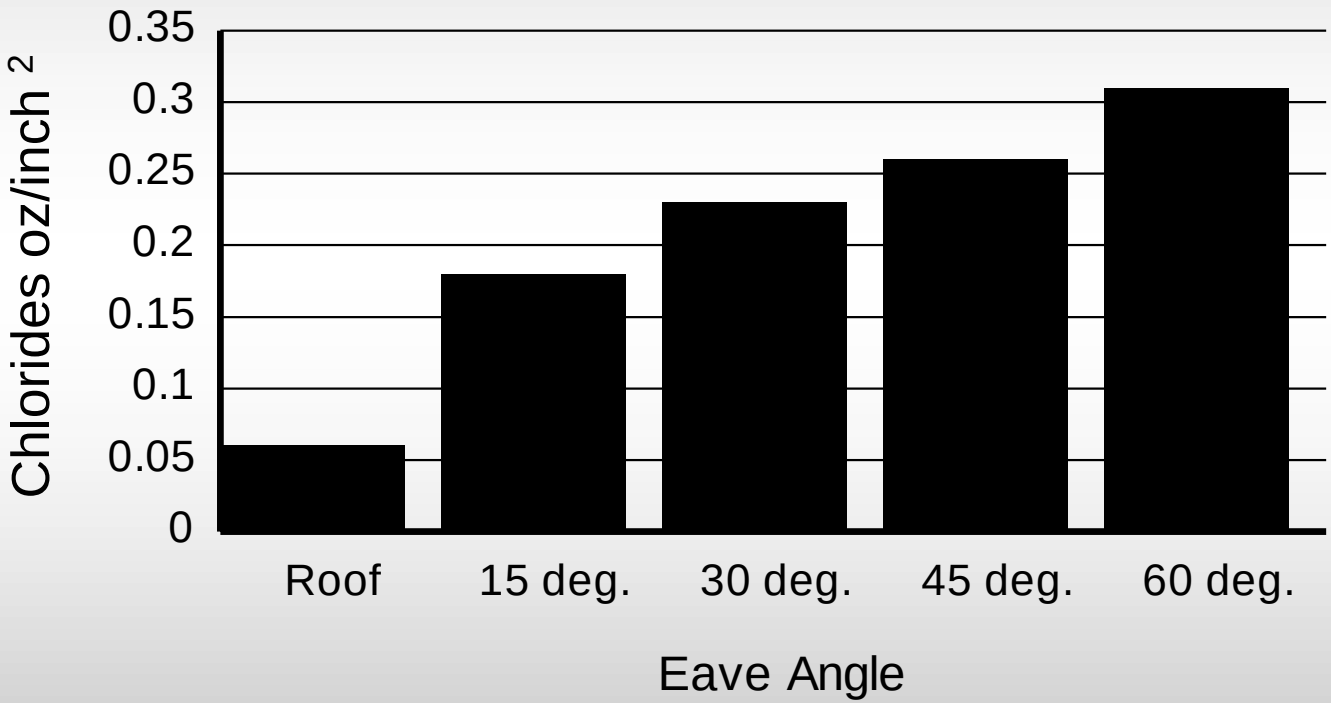
Chloride Accumulation In Sheltered Locations





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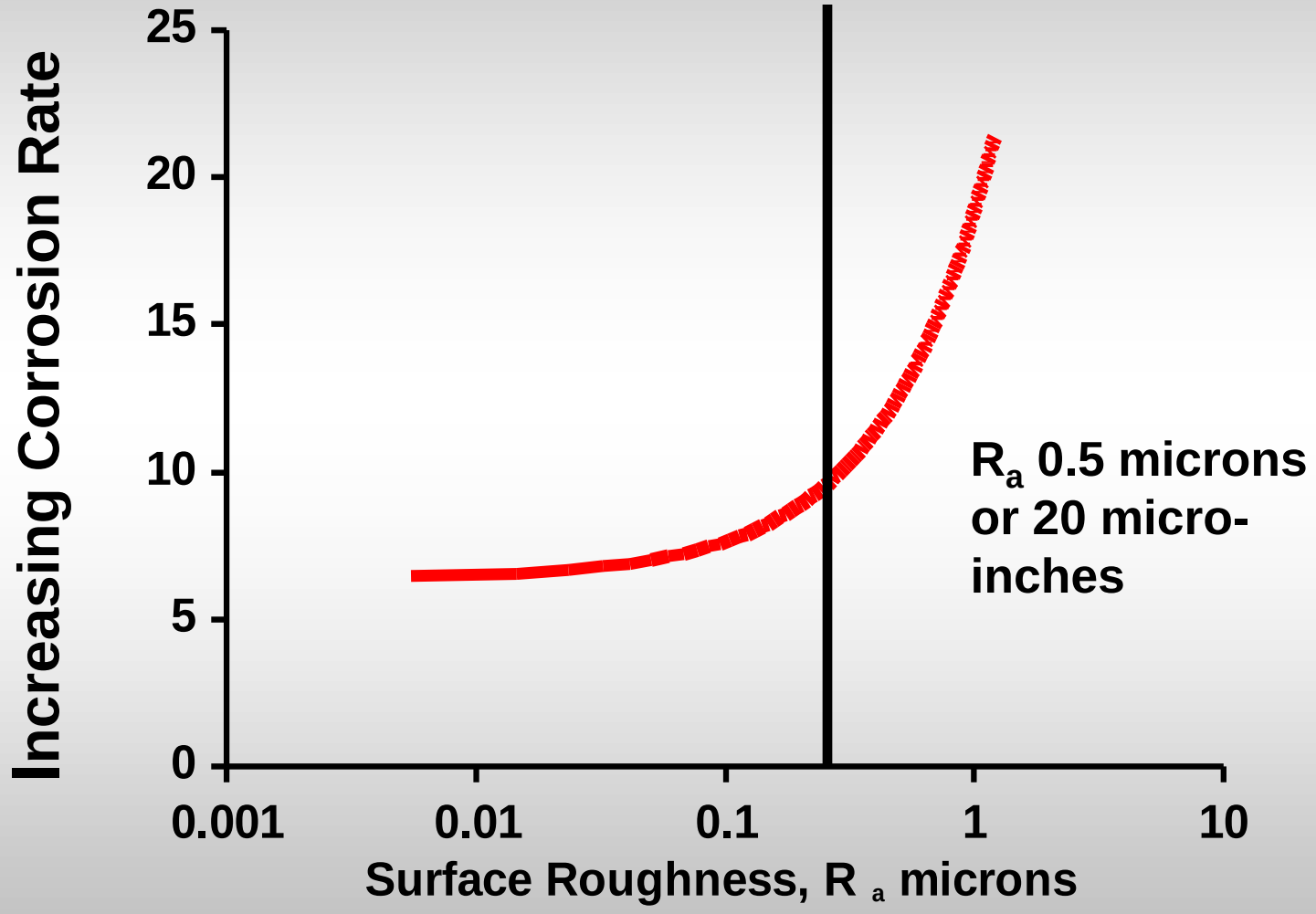
Surface Finish
As Critical As Stainless Steel Selection



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Typical Sheet Surface Roughness Range

Finish	2D	2B	BA	No. 4	Hair-line	No. 7	No. 8	Super No. 8
R_a Micro-inch	5 - 39	2.4 - 20	0.5 - 4	7 - 25	5.5 - 8.0	2.4 - 8	0.8 - 4	0.4 - 0.8
R_a Micron	0.13 - 1.0	0.06 - 0.5	0.01 - 0.10	0.18 - 0.64	0.14 - 0.2	0.06 - 0.2	0.02 - 0.10	0.01 - 0.02

Evaluation Scores

Section	Cheung Kong	Railings
Pollution	3	3
Coastal salt	3	5
Weather	0	0
Design	-1 or -2	2
Maintenance	-2	-3
Total	**2 or 3**	**7**

Available at www.imoa.info

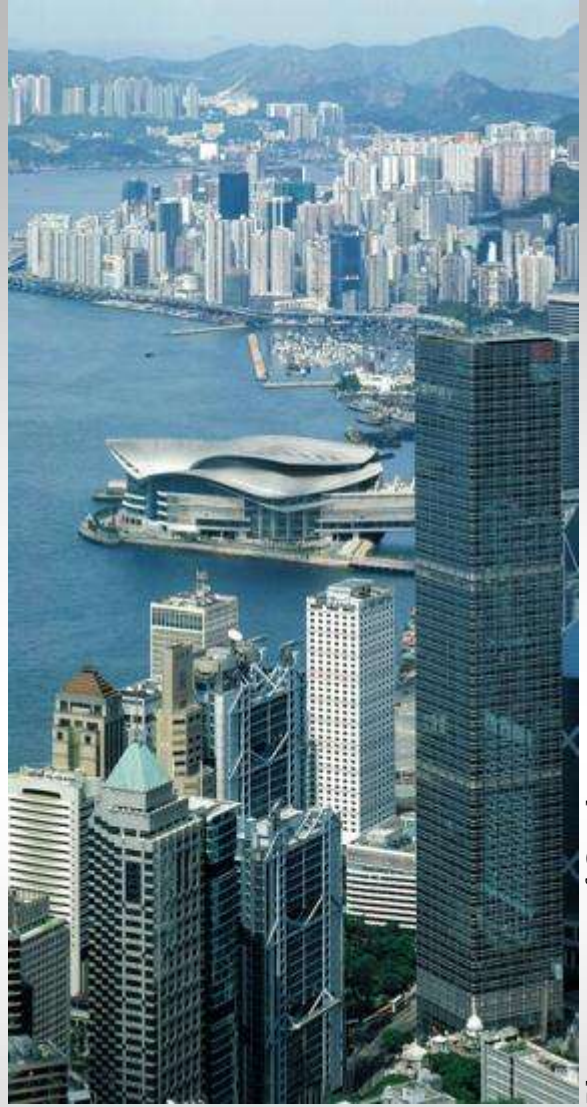

Photo courtesy of Outokumpu

Cheung Kong Center, Type 316

Photo courtesy of Nickel Institute

Hong Kong Convention Center railings, Type 316

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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

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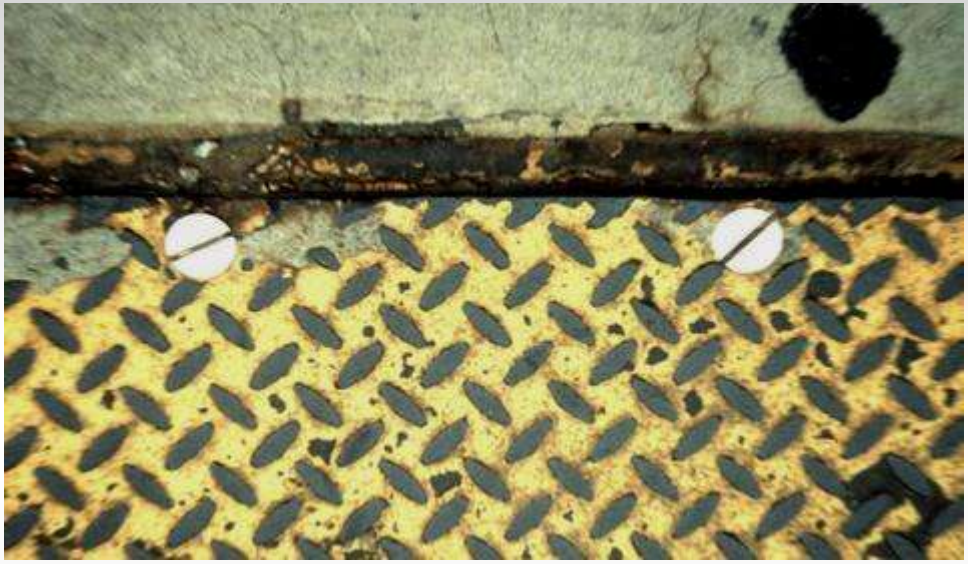
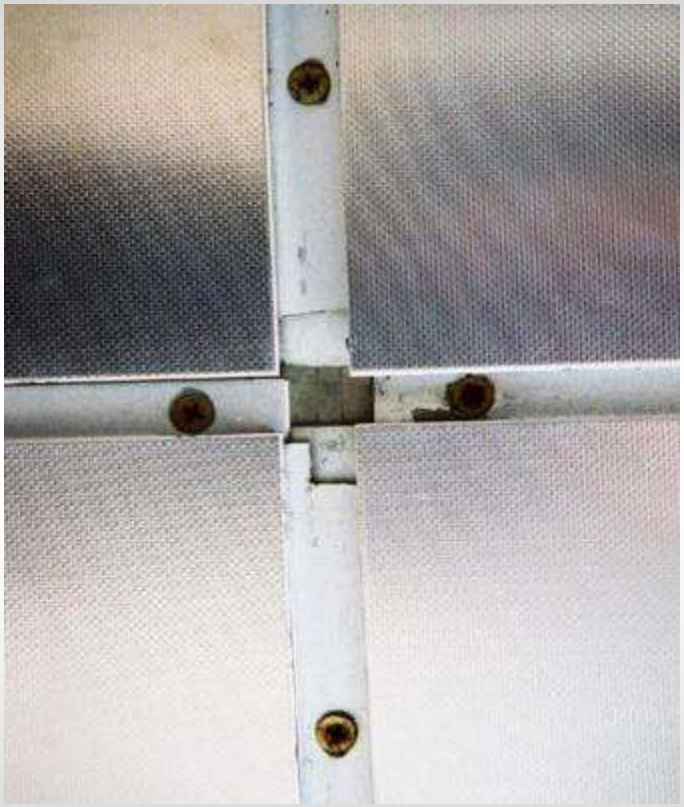
Surface Area Ratio Affects Potential For Corrosion





Photos courtesy of Nickel Institute

Good ratio = no impact on corrosion

- Stainless steel fasteners in carbon steel

Bad ratio = rapid corrosion

- Galvanized fasteners in stainless steel

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Sites for Crevice Corrosion

If the design will be exposed to salt (chlorides) and moisture, avoid crevices or seal them to prevent corrosion

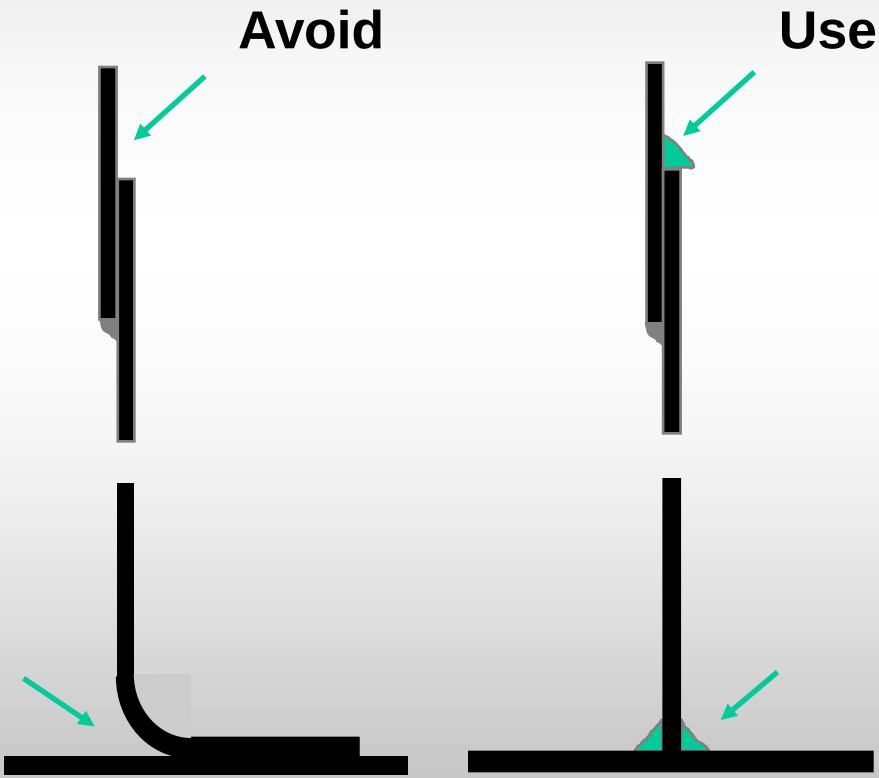

Photo courtesy of Nickel Institute

Prevent Carbon Steel Contamination

- Protective surface - removable UV rated film
- Store components off site until installation
- Clean tools and equipment
- Do not use
  - Carbon steel brushes, wool, shot
  - Media used on carbon steel or iron
- Do not grind carbon steel near stainless
- Require certification that surfaces are free of contamination

Photo courtesy of Nickel Institute

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Sea Walls & Pier Concrete Corrosion

Sidney Opera House
Carbon steel reinforced concrete retaining wall corrosion
Replaced with Type 316 rebar

Stainless Steel Finishes

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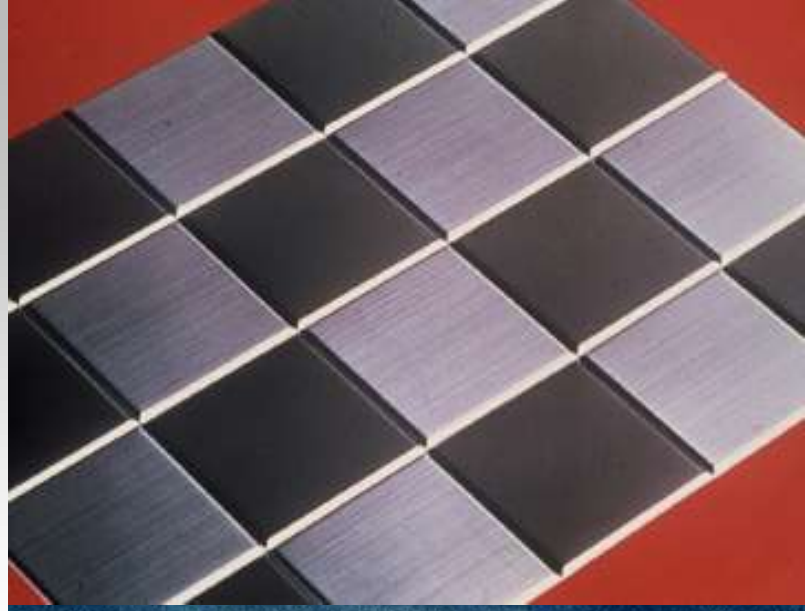
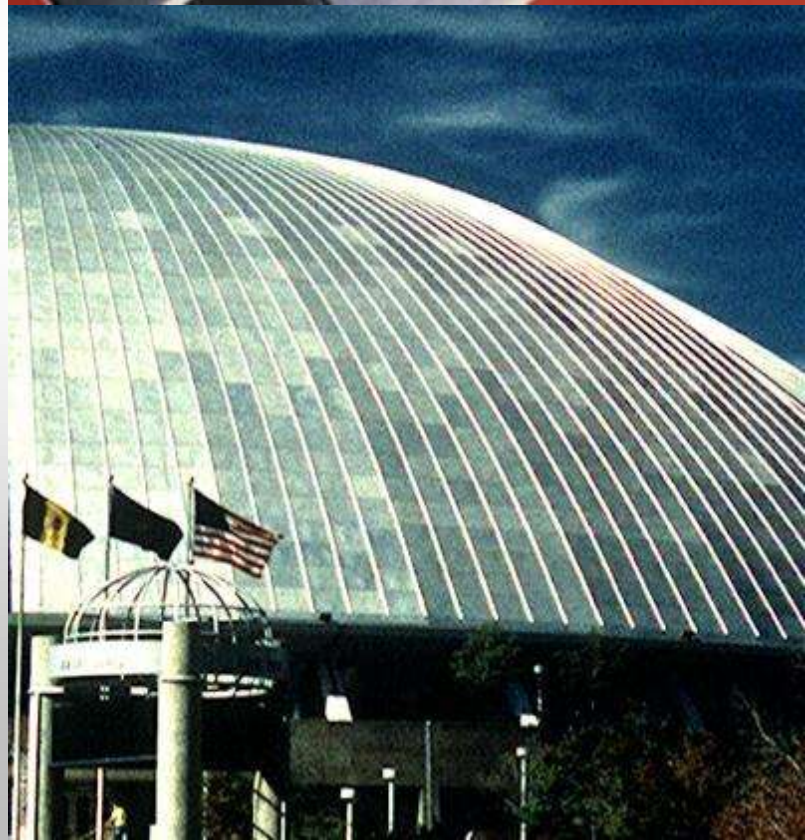
Obtaining a Uniform Appearance

- 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





No. 4 Finish Design Example

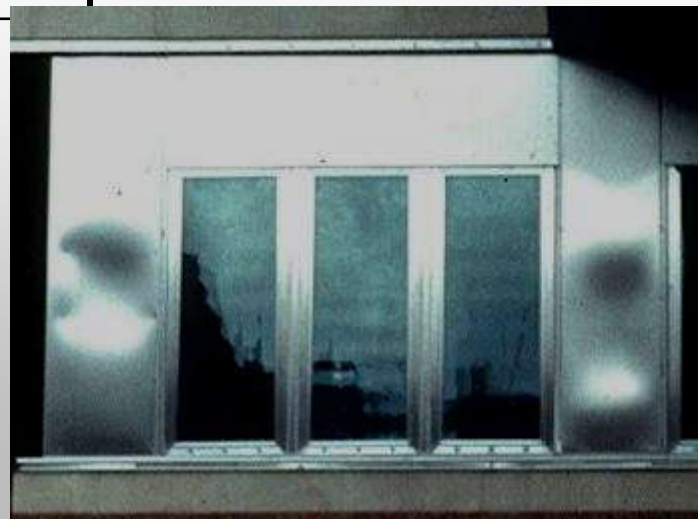
Achieving Flatness

- Use adequate panel thickness

Column Covers	2 – 2.8 mm
Wall panels	0.5 – 3 mm
Roofing, supported	0.5 – 0.6 mm
Countertops	2 - 2.8 mm

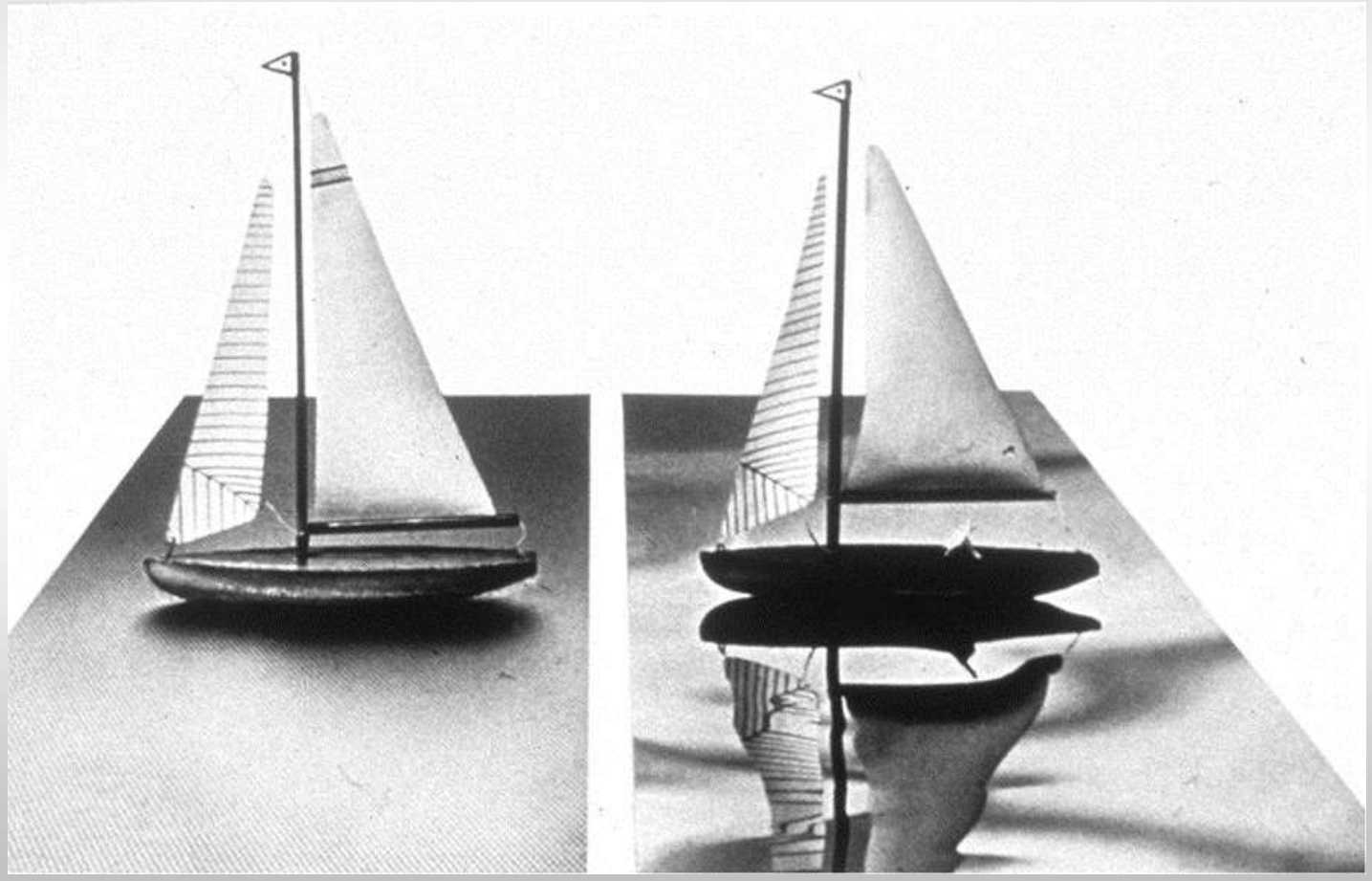
- Avoid long or wide unsupported panels

Metal	Thermal Expansion $^{o}C \times 10^{-6}$	Thermal Conductivity *(W/m-C)*
Type 304/316	16.9	0.16
2205	13	0.23
Carbon steel	12	0.54
Alloy 400	13.9	0.26
Copper	16.9	3.86
AA 3003	23.2	2.04



Dull or Embossed Finishes Look Flatter Than Reflective Finishes

- Both samples are equally flat



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Flat Unlaminated Panels

Reflectivity	Width-to-Thickness Ratio
High	150 max.
Medium-to-low	200 max.
Coined/Embossed	200 or higher

No. 2D Mill Finish

- Low reflectivity, semi-matte, uniform silver-gray
- 2D for roofing has final pass through dull rolls
- Not repairable
- Susceptible to fingerprinting
- Primary use - roofing
- Surface roughness
  - R_a 5.0 to 39.0 micro-inches (0.13 to 1.0 microns)
  - Roofing gauges are usually under R_a 20 micro-inches

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Singapore Turf Club Architect: Ewing Cole

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No. 2B Mill Finish

- Smoother and more reflective than No. 2D
- Significant finish variation
  - Cloudy to mirror-like
- Susceptible to fingerprints
- Flashing, roofing, starting point for other finishes
- Surface roughness
  - 2.4 to 20 micro-inches (0.06 to 0.51 microns)

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Bright Annealed (BA)

- Buffed BA
- Highly reflective, mirror-like
- No apparent polishing lines
- Ornamental trim finish
- Minor scratches removable by buffing
- Surface roughness
  - 0.5 to 4.0 micro-inches (0.01 to 0.10 microns)

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No. 4 Polish

- Directional, short parallel lines
- Repairable
- Conceals minor scratches
- Applied with abrasive belts (120 to 320 grit)
- Wet or dry polishing
- Significant variation in corrosion performance
- Surface Roughness
  - Ra 0.18 to 0.64 microns

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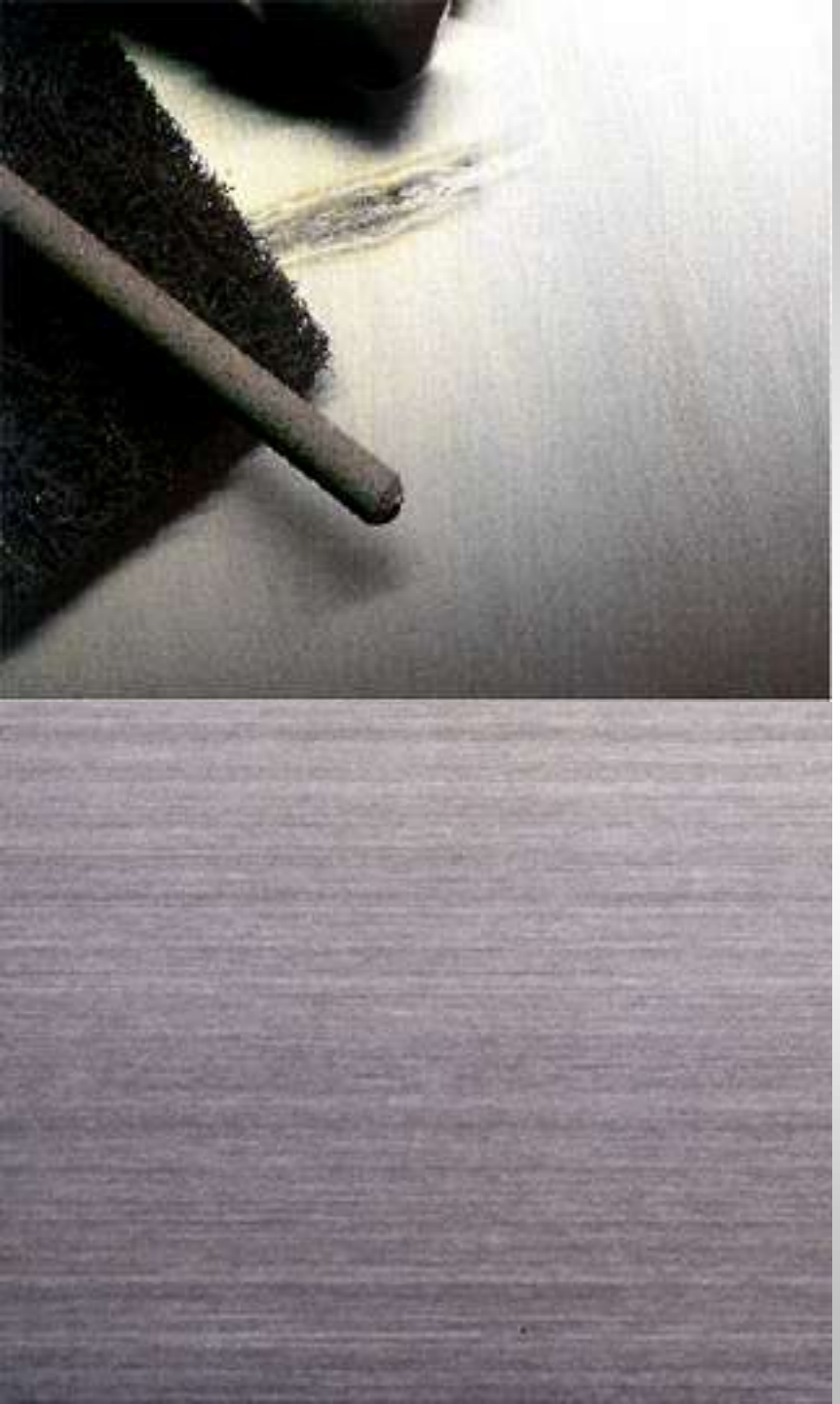

Hairline

- Directional, long fine parallel lines
- Applied with Scotch-Brite® (non-metallic abrasive pads)
- More reflective than No. 4
- Repairable – often used for refinishing
- Rolled-on version available
- Surface roughness
  - R_a 0.14 to 0.20 microns

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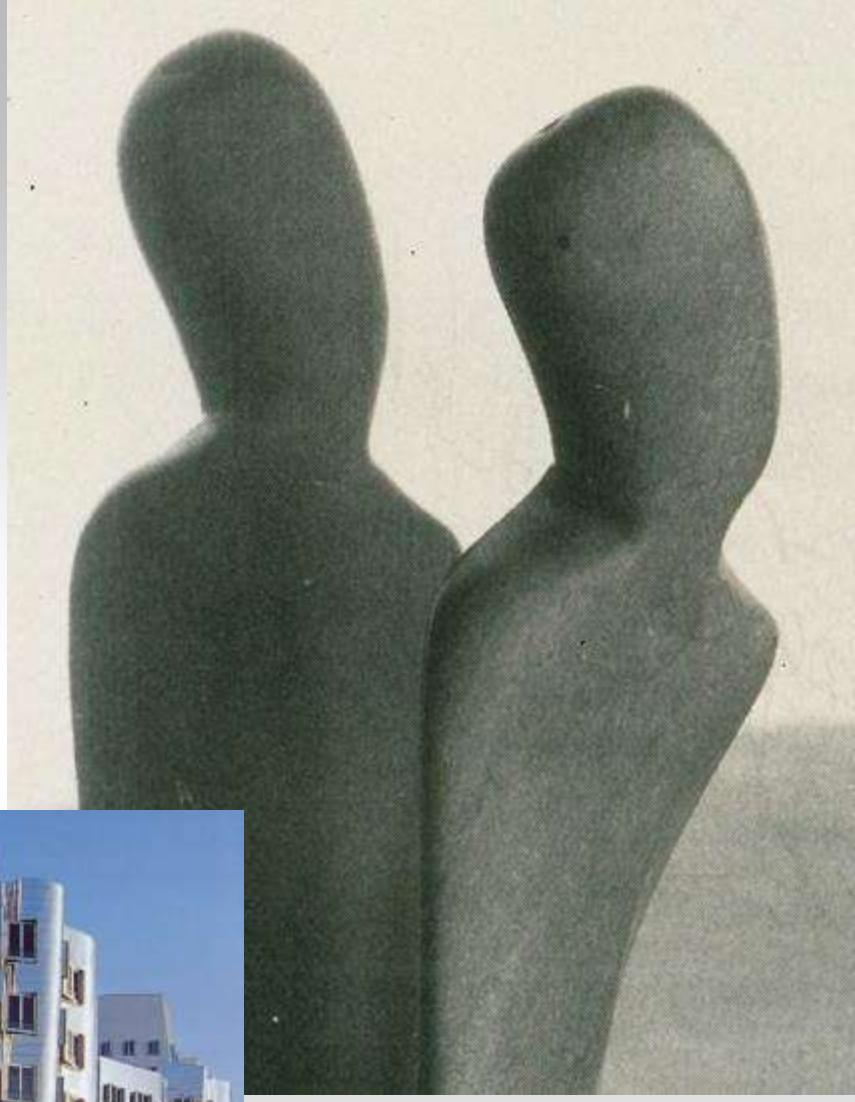
No. 8 Polish

- Mirror-like
- Very fine lines visible upon close examination
- Fine No. 4 polish followed by about 15 to 20 minutes buffing
- R_a 0.02 - 0.10 microns



Neuer Zollhofs, Dusseldorf, Germany

Super/Supreme No. 8, 9, 10, 11, 12

- Mirror finish, no visible grit lines
- Abrasive polishing plus up to 60 minutes buffing
- Not in ASTM A 480
- Surface roughness
  - R_a 0.01 - 0.20 microns

Low Sulfur

- For standard finishes specify “low sulfur”
  - 0.005% or less
  - Improved corrosion performance
  - Finish appearance
- For mirror finishes
  - Specify 0.002% or less
- Low sulfur tube and pipe may not be available
  - Sulfur makes high speed welding easier

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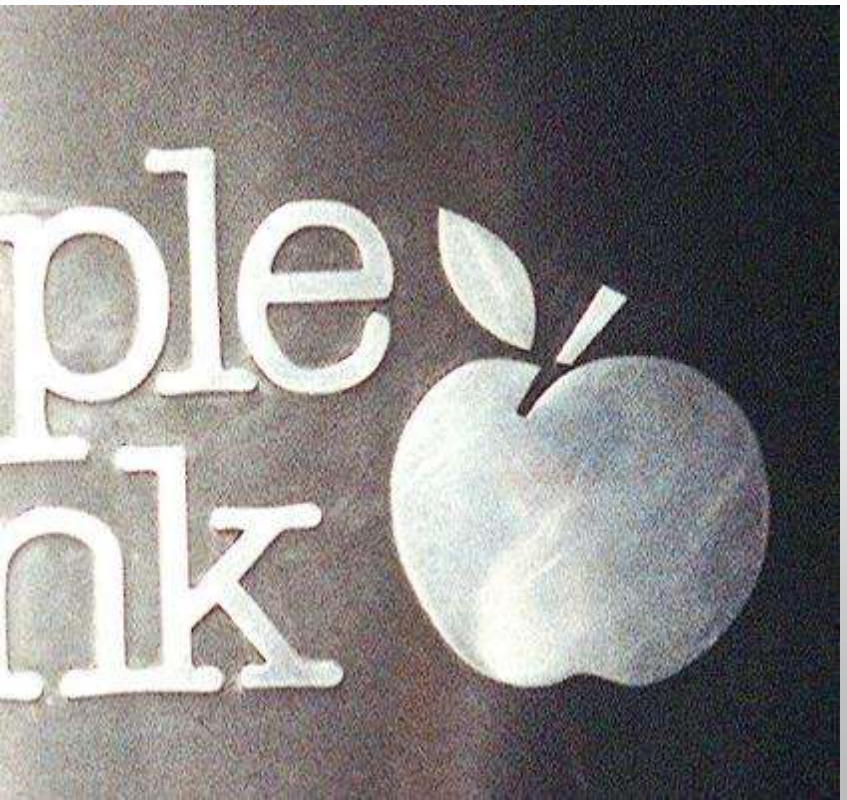

Acid Etching

- A protective coating is applied selectively to the surface using silk screening or other methods
- 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

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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

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Walt Disney Concert Hall, Los Angeles

Gehry Partners

Type 316, vibration and mirror polished finishes

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Distressed Finish
(pre-vandalized)

- Non-directional
- Applied over mirror or bright annealed finish
- Grinding wheel or coarse stainless wire brush
- Coarse scratch pattern
- Appearance may not be uniform
- Use control samples

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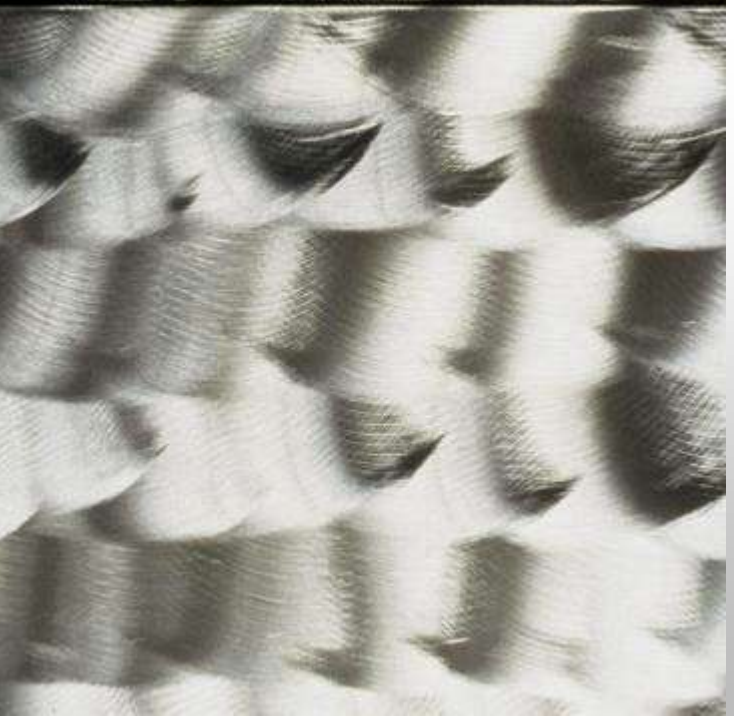

Swirl Finishes

- Applied over 2B or 2D finish
- Grinding wheels or stainless wire brushes
- Swirl patterns
- Use control samples

Proprietary Mechanical Finishes




Pattern Polish Finishes
Courtesy Main Steel Polishing, Scott Pease Photographer

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Engine-Turned Finishes

- Small circular lines, rings, or overlapping complete circles
- Circles range from 1/2- to 12-inch (13 - 305 mm) diameters
- Applied over a mirror finish
- CNC machines control spinning abrasive disks

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Abrasive Blasted Finishes

- Non-directional and repairable
- Surface distortion if panels are too thin
- Texture and color vary with blast media
- Susceptible to fingerprinting
- Clean surface before and after blasting
- Always use clean blast media

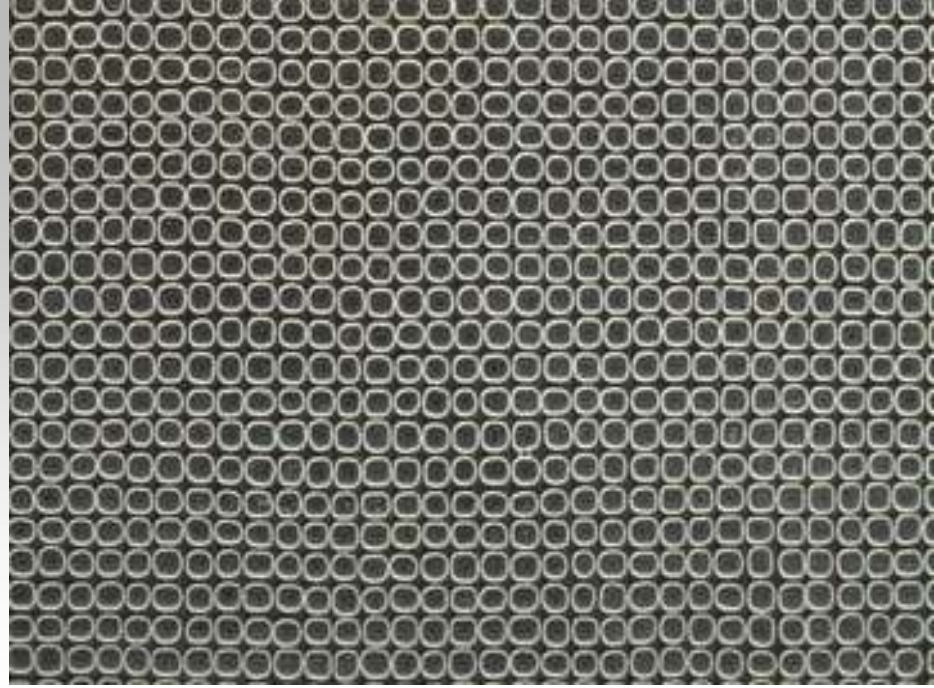
Effect of Abrasive Blast Media

Fine sand	Dark, coarse
Glass beads	Light, smooth, grainy
Silicon carbide	Dark, coarse
Stainless shot	Small, curved indentations
Ground quartz	Shiny, coarse, angular indentations

Liner Museum Appenzell, Switzerland 3 mm glass bead blasted

Embossing and Coining

- Applied by passing a stainless steel coil between two rolls
- Coining
  - One roll is patterned
  - One roll is smooth
- Embossing
  - Both rolls are patterned



Jin Mao Building, Shanghai

Skidmore, Owings & Merrill

421 m or 88 stories

220 tons Type 316

Vertical spine panels
1.5 mm, coined
Cambric, bright
annealed

Tubular features,

No. 4 polish

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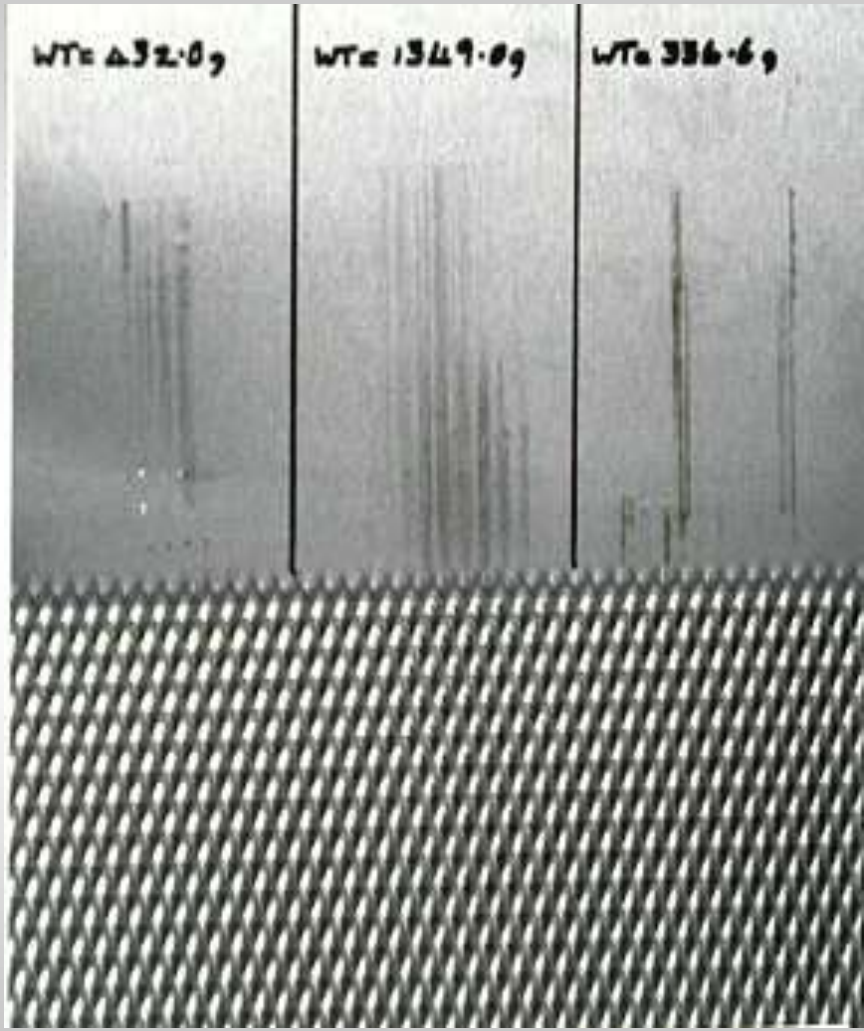
Embossing and Coining

- Increases rigidity and impact resistance
  - Light patterns 10 to 15%
  - Heavy patterns up to 35%
- Conceals scratches and reduces scratch depth
  - Increased surface hardness
  - Uneven surface breaks up visible line



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Rolled-On Finishes

Can mimic abrasive blasted finishes

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Electrochemical Colors

Obtained by thickening the passive film

Color can be uniform or deliberately varied

Often called “interference” or “living” color

Bronze Blue Gold Red
Purple Black Green

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1975

Shakaden Temple, Japan

Completed 1975

Electrochemically colored

Black roof with gold dots and clips

2010

no change in color

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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

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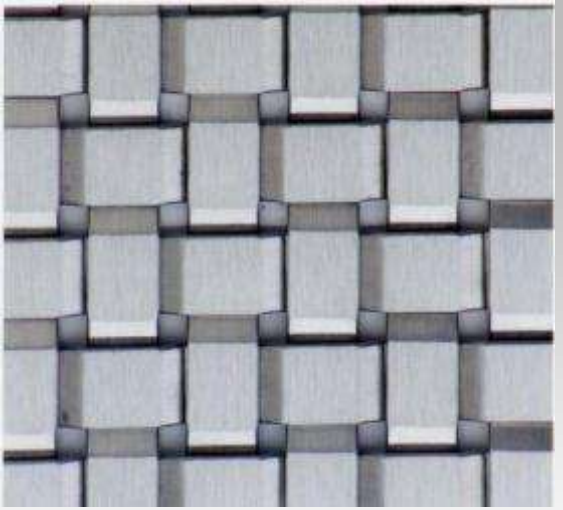
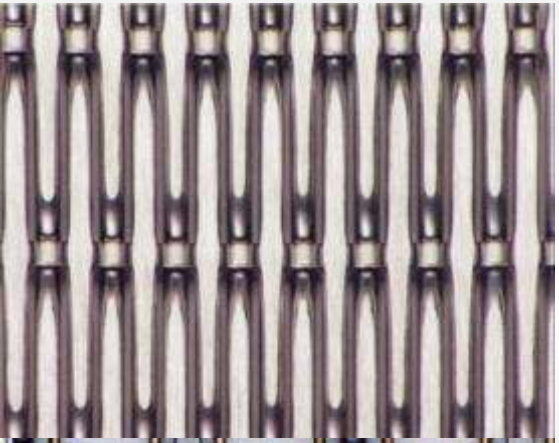
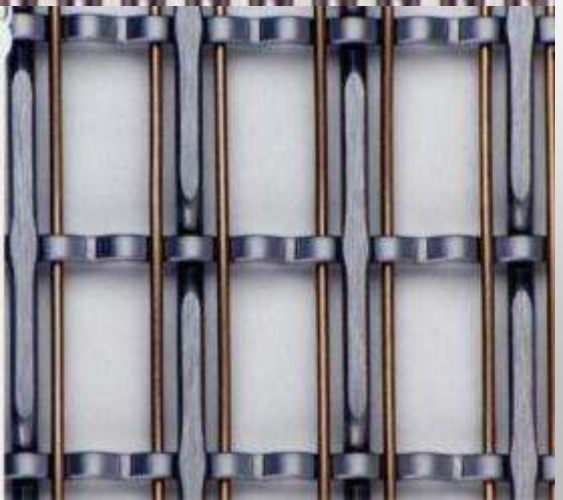
Perforated Stainless







Woven Stainless

- Broad range of styles and weights
- Hide scratches
- Impact resistant
- Adds tactile and visual texture
- Interior and exterior applications
  - Ceilings
  - Walls
  - Room dividers
  - Furniture
- Salt (chloride) crevice corrosion must be considered

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