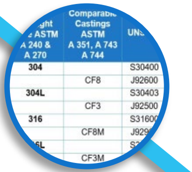
Hygienic Materials of Construction and Surface Treatments

Gabe Miller

Learning Objectives

Classify hygienic properties of materials

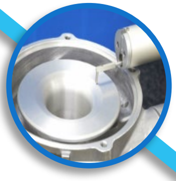
Review common metal failures



Identify metal properties

Identify plastic and elastomer properties

Review plastic and elastomers common failures



Classify surface finishes and treatment methods

Hygienic Design Process for Equipment

- Define Intended Uses & Risks
- Define Cleaning Method
- Define Product Surfaces
- Select Approved Materials of Construction
- Design & Build to Meet Hygienic Criteria

Select Approved Materials of Construction

Type of the Material

Metal
Plastic
Elastomer
Other

Hygienic Properties

Physical Properties
Mechanical Properties
Operational properties

Hygienic Requirements: Materials of Construction

Physical Properties

- Inert
- Nontoxic
- Non-Corrosive
- Non-Porous

Mechanical Properties

- Durable
- Smooth
- Free of Cracks and Crevices

Operational Properties

- Cleanable
- Stable in Temp. & pH Limits
- Product Compatible
- Reduced Maintenance

Hygienic Material: Physical Properties

INERT	Little or no ability to react with products or cleaning chemicals
NONTOXIC	Not poisonous to product or people
NON-CORROSIVE	Material is not eroded or damaged from a chemical action
NON-POROUS	Does not have minute spaces/holes that air or liquid can pass through

What's Wrong With This Picture?

Corrective Actions

Hygienic Material: Mechanical Properties

DURABLE	Ability of a material to withstand wear, pressure or damage in the application of intended use for the life of the application
SMOOTH	Material surfaces are smooth as manufactured or be made smooth with surface treatments
FREE OF CRACKS AND CREVICES	Surfaces do not have cracks and crevices as a result of manufacturing processes or normal use in the intended application

Hygienic Material: Operational Properties

CLEANABLE	The material is suitable for cleaning and sanitizing to a microbiological level with standard cleaners and sanitizers
STABLE	The material is stable within temperature and pH limits of product, cleaners, and sanitizers
PRODUCT COMPATIBLE	The material is compatible with the product during all phases of the process
REDUCED MAINTENANCE	The material is capable of being maintained in a hygienic condition with little or no routine maintenance

Question 1 - Test your knowledge?

An important operational material property is the material is stable within temperature and pH limits of product, cleaners, and sanitizers.

- **A.** True
- **B.** False

Material Certificates

- Material suppliers shall provide written material certificates for all materials:
  - Metals
  - Non-metals
  - Lubricants
  - Coatings
  - Chemicals
- Material Certificates contain:
  - Verification of material composition
  - Regulatory status of an individual substance of material

3-A Sanitary Standards for General Requirements

American National Standard

ANSI
American National Standards Institute

ANSI/3-A 00-01-2017

Metals in 3-A General Requirements, Appendix 1

Nominal Composition Tables are Provided for Each Metal

STAINLESS STEELS

- Wrought 304 and 316/316L
- Non-Galling
- Precipitation-Hardenable
- Duplex
- Superaustenitic
- Nickel-Chromium-Molybdenum

TITANIUM

- Grade 2 Food Grade Titanium

Common Metal Failures

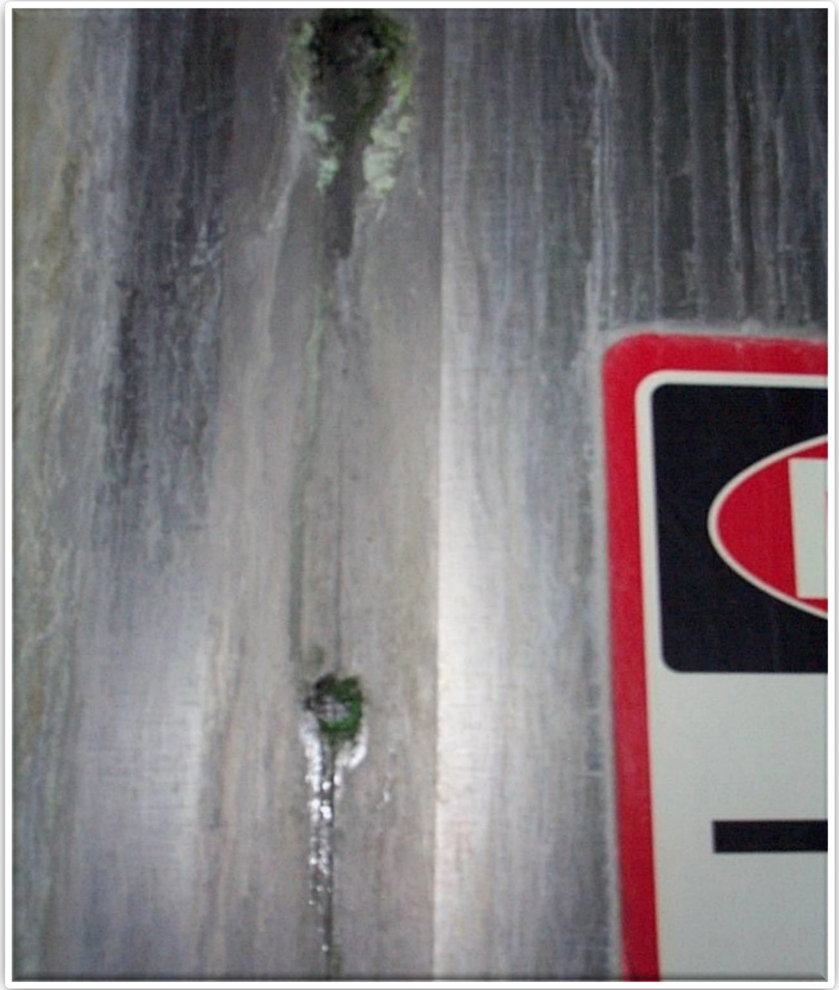
Corrosion

Galling

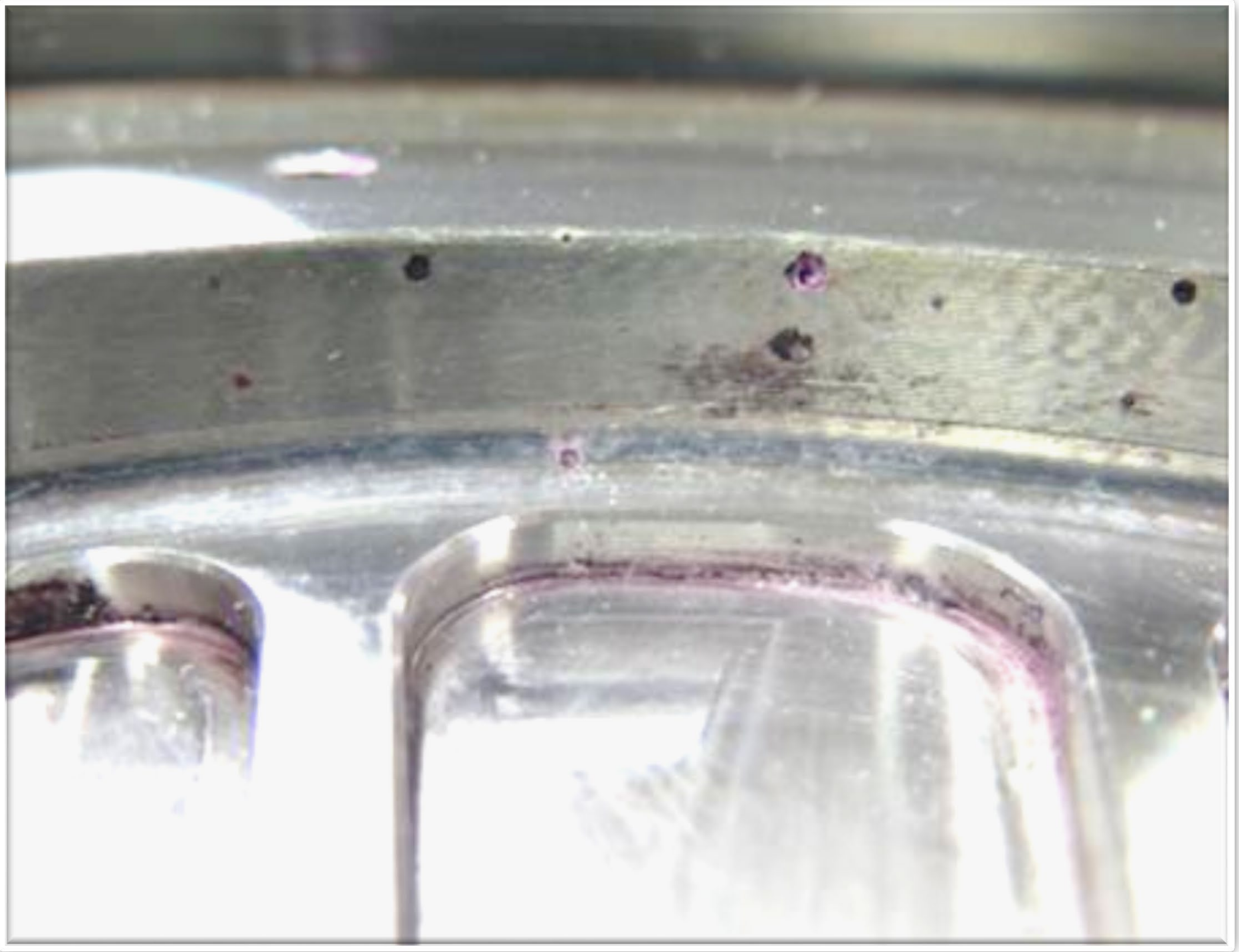
Surface Wear

Mechanical Failure

Hygienic Risk Caused by Corrosion Failure



Hygienic Risk Caused by Pitting Corrosion



Galling

Pitting Resistance Equivalent Number (PREN)

What is PREN?

A predictive measurement of the corrosion resistance of types of stainless steel

PREN Formula

PREN = %Cr + (3.3 x %Mo) + (16 x %N)
Note: 304 SS = 18.1 / 316 SS = 24 (approximately)

PREN is a Base Metal Composition of:

Cr = Chromium
Mo = Molybdenum
N = Nitrogen

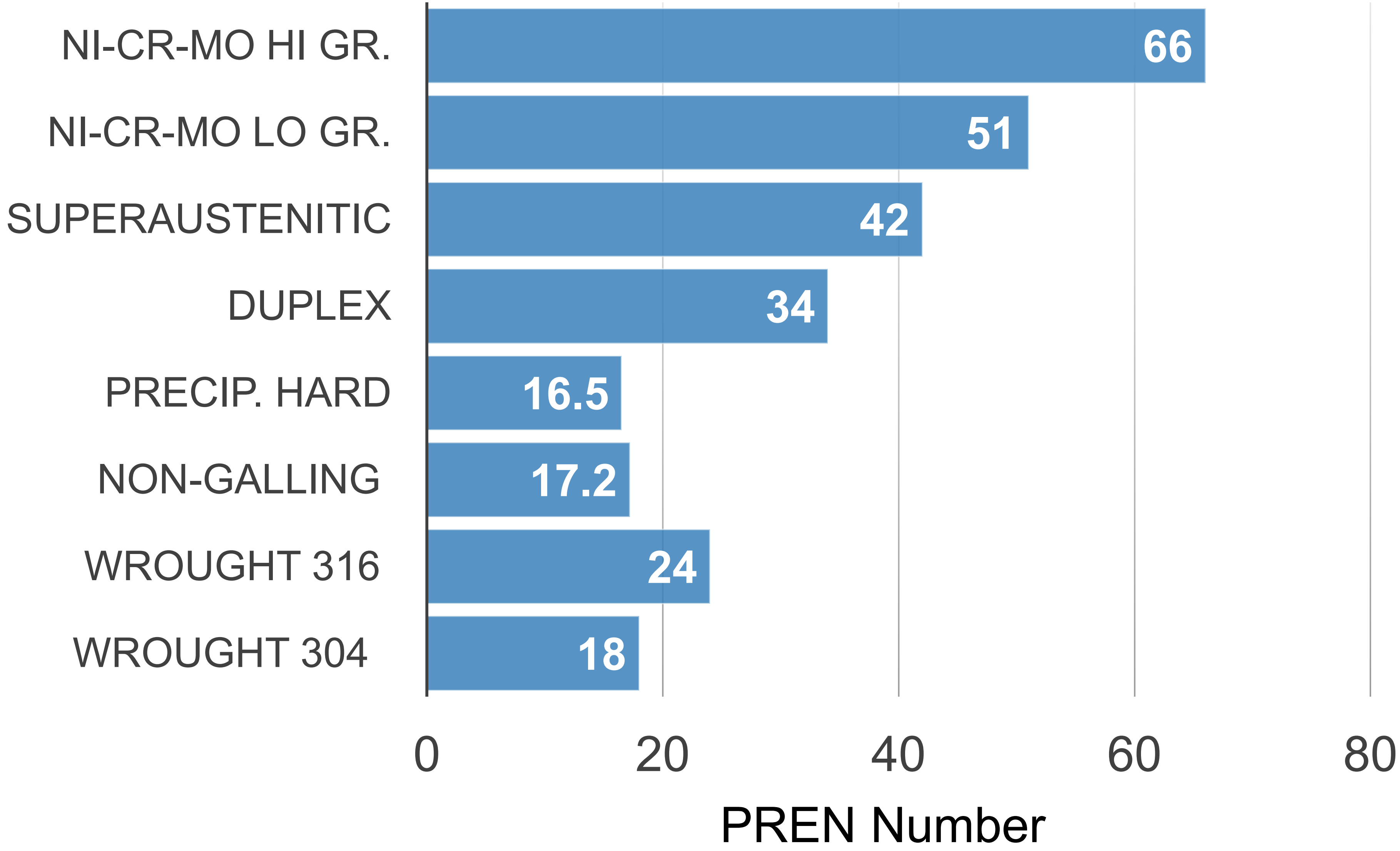
PREN formula does not apply to Titanium

Question 2 - Test your knowledge?

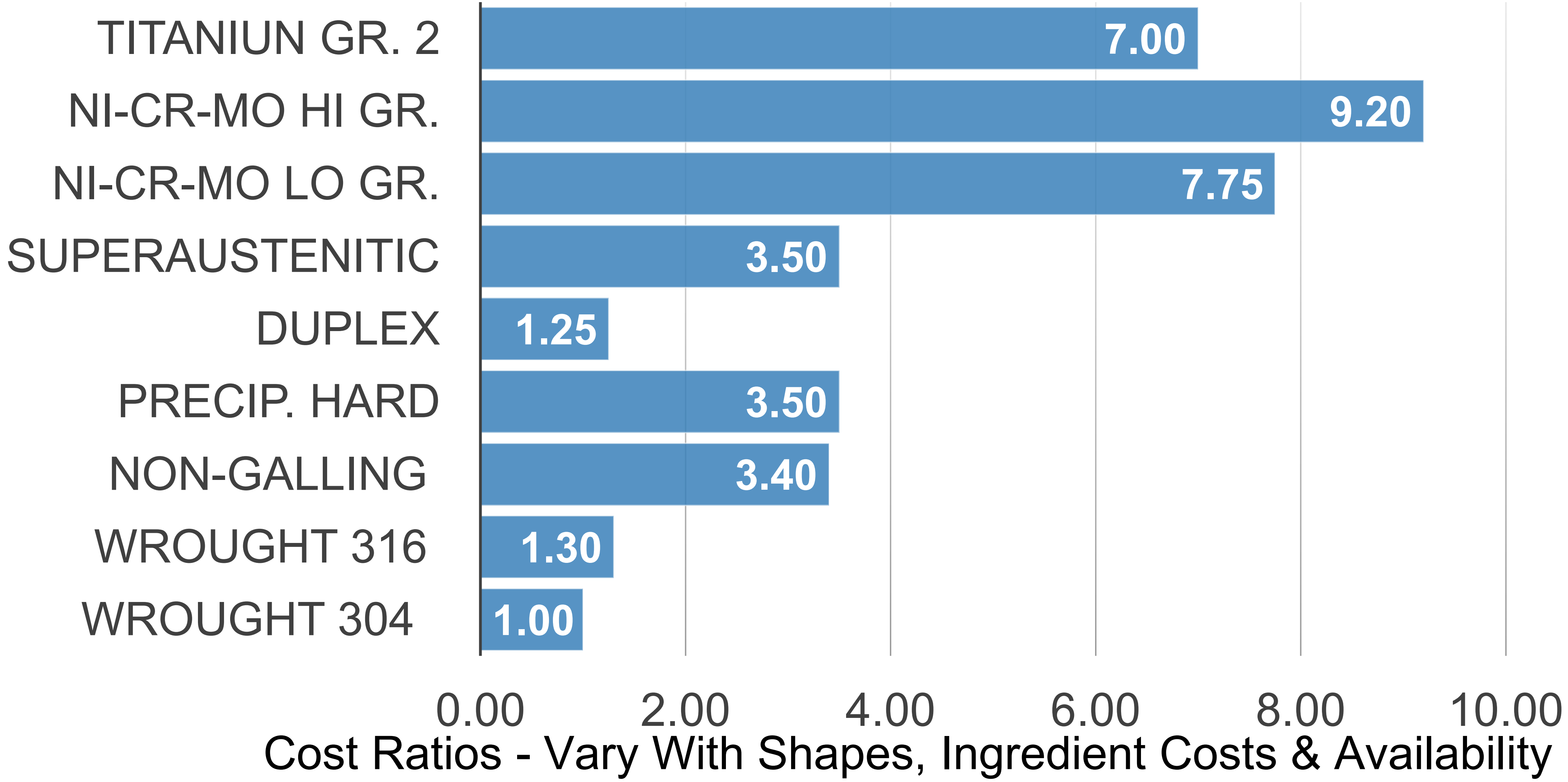
"*3-A Sanitary Standards for General Requirements*" lists stainless and ________________ as recommended product contact metals approved for hygienic equipment.

- **A.** Brass
- **B.** Copper
- **C.** Titanium
- **D.** Bronze

Corrosion Resistance PREN Number

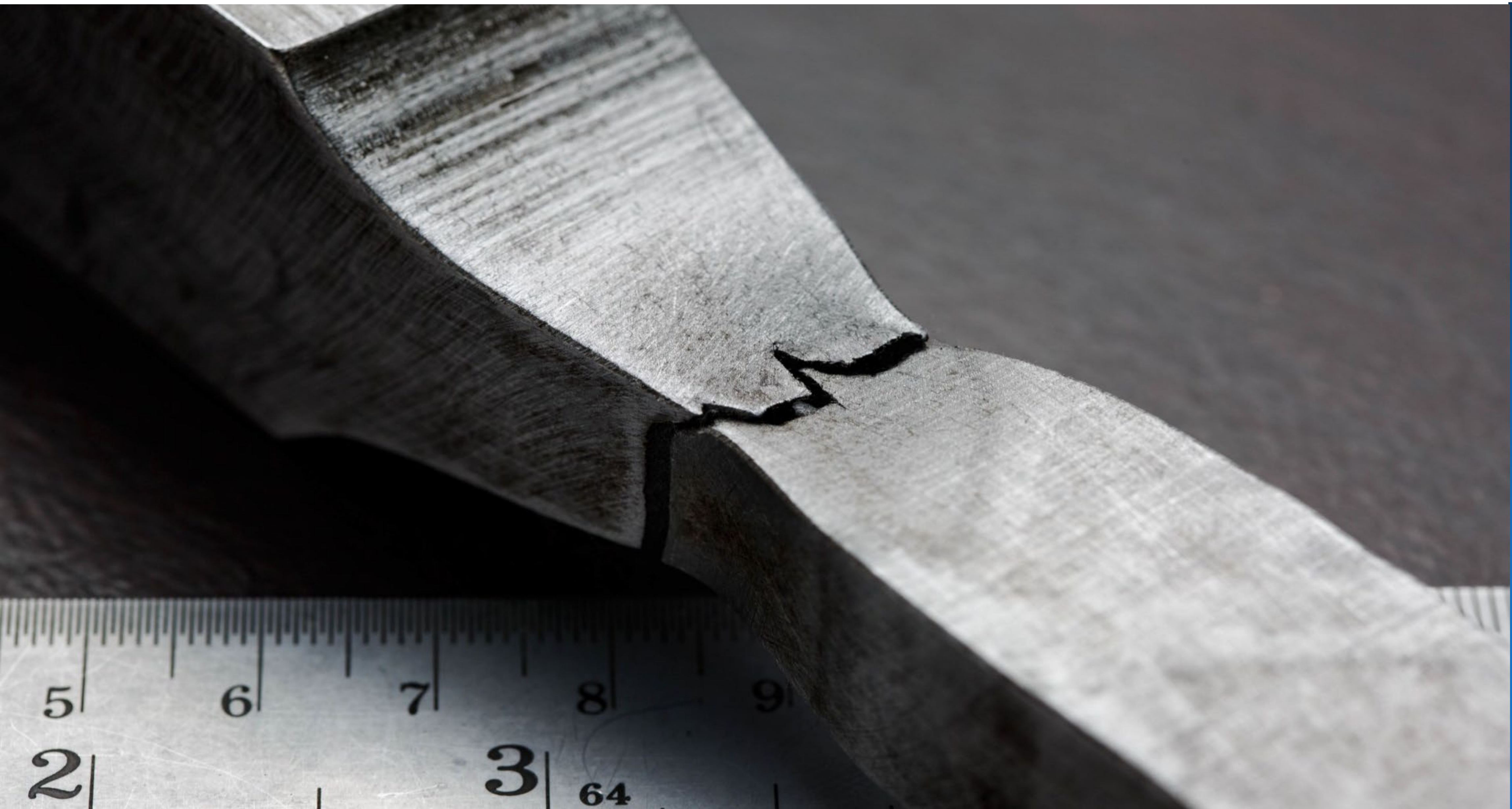


Cost Ratio (Compared to 304 Stainless Steel)



Galling Damage Creating a Hygienic Risk from Two Moving Parts Wearing

Exceeding Tensile Strength of Material



304 & 316 Stainless Steel Table from Appendix 1

Nominal Composition

Typical Wrought Type ASTM A 240 & A 270	Comparable Castings ASTM A 351, A 743 A 744	UNS No.	Carbon	Cr	Ni	Fe	Mo
304		S30400	0.08 Max	18.2	8.2	Bal.	
	CF8	J92600	0.08 Max	18.2	8.2	Bal.	
304L		S30403	0.03 Max	18.2	8.2	Bal.	
	CF3	J92500	0.03 Max	17.2	8.2	Bal.	
316		S31600	0.08 Max	16.7	11.2	Bal.	2.2
	CF8M	J92900	0.08 Max	18.2	9.2	Bal.	2.2
316L		S31603	0.03 Max	16.7	11.2	Bal.	2.2
	CF3M	J92800	0.03 Max	17.2	9.2	Bal.	2.2

Table 1. Wrought and Cast Stainless Steel Alloys Most Commonly Used

304 Austenitic Stainless Steel

- Commonly called 18-8
- Corrosion-resistant to most food applications and cleaning solutions
- Durable
- Excellent welding properties
- Easily formed & machined
- Work hardens with machining and forming
- Good surface roughness with cold-rolled sheet
- Economical and readily available

Property	Relative Value
Ultimate Strength	75 ksi
Yield Strength	30 ksi
Elongation	40%
Hardness HRB	92
PREN	18

316 Austenitic Stainless Steel

- More corrosion-resistant than 304
- Subject to pitting & crevice corrosion in warm chloride environments
- Tough & durable
- Excellent welding properties
- More difficult to form & machine than 304
- Work hardens with machining and forming
- Good surface roughness with cold-rolled sheet
- More expensive than 304, readily available

Property	Relative Value
Ultimate Strength	75 ksi
Yield Strength	40 ksi
Elongation	40%
Hardness	95
PREN	24

Wrought Stainless Steel - Nominal % Element Composition*

Metal	ID	C	Cr	Ni	Fe	Mo	Mn	Si	N	Cb	Cu	W
304 SS		.08	18.2	8.2	Bal							
316 SS		.03	16.7	11.2	Bal	2.2						
Non-Galling	N-60	.10	17.5	8.5	Bal		8.0	4.0				
Prec. Hard	17-4ph	.07	16.5	4,0	Bal					0.3	4.0	
Duplex		.03	22.5	5.5	Bal	3.0			0.2			
Super. Aust.	AL-6X	.03	21.0	24.5	Bal	6.5			0.2			
Super. Aust.	254	.02	20.0	18.5	Bal	6.5			0.2		0.75	
Ni-Cr-Mo	625	.01	21.5	Bal	5.0	9.0				3.5		
Ni-Cr-Mo	C-22	.015	21.5	Bal	4.0	16.0						3.0

*These are nominal value, verify actual numbers with individual supplier with 3-A SSI Appendix Charts

Question 3 - Test your knowledge?

316 SS is more corrosion resistant than 304 SS because it contains this element?

- **A.** Copper
- **B.** Iron
- **C.** Molybdenum
- **D.** Tungsten

Wear and Galling Resistant Stainless Steels

- Standard austenitic metals tend to gall
- Gall under sliding high pressure
- Add silicon and manganese
- Excellent wear and galling resistance
- Satisfactory performance in dairy industry
- Not as corrosion resistant as type 304 in aggressive environments

Property	Relative Value
Ultimate Strength	100 ksi
Yield Strength	45 ksi
Elongation	40%
Hardness	Varies
PREN	16.5

Precipitation-Hardenable (PH) Stainless Steels

- Used when harder metals are required
- Can be heat treated
- Satisfactory performance in dairy industry
- Not as corrosion resistant as type 304 in aggressive environments
- After heat treatment 17-4 PH hardness is 2-3 times higher

Property	Relative Value
Ultimate Strength	100 ksi
Yield Strength	45 ksi
Elongation	40%
Hardness	
PREN	17

Duplex Stainless Steels

- Type 2205 is the most common
- Half austenite and half ferrite structure
- Twice the yield strength of 304 SS
- Reduced material thickness and weights
- Readily weldable
- More difficult to form and machine
- Good resistance to pitting & crevice corrosion
- Excellent resistance to stress-corrosion
- More stable pricing
- Some shapes & sizes are harder to source

Property	Relative Value
Ultimate Strength	90 ksi
Yield Strength	65 ksi
Elongation	25%
Hardness HRB	217
PREN	34

Superaustenitic Stainless Steels

- More chrome, nickel, molybdenum
- Suited for high chloride environments
- High resistance to pitting, crevice corrosion
- 50% stronger than 300-series austenitic stainless steels
- Excellent impact toughness
- Excellent workability and weldability
- Relatively expensive, yet more economical than high nickel-based alloys
- Some shapes & sizes are harder to source

Property	Relative Value
Ultimate Strength	100 ksi
Yield Strength	45 ksi
Elongation	35%
Hardness HRB	96
PREN	42

Nickel-Chromium-Molybdenum Alloys

- Highest corrosion resistance
- Excellent resistance to pitting and crevice corrosion
- Suited for high chloride hot environments
- Contain high level of chromium and molybdenum
- 60 to 65% nickel content
- Moderate to difficult to machine
- Readily weldable to special procedure
- Some shapes & sizes are harder to source
- Very expensive

Property	Relative Value
Ultimate Strength	100 ksi
Yield Strength	45 ksi
Elongation	40%
Hardness	93
PREN	68

Titanium Alloys

- High resistance to pitting and crevice corrosion
- Special food applications
- Only food grade titanium shall be used
- Plate heat exchangers
- Easily formed and welded
- Very lightweight
- High strength to weight ratio
- Very expensive

Property	Relative Value
Ultimate Strength	50 ksi
Yield Strength	40 ksi
Elongation	20%
Hardness HRB	82
PREN	N/A

Alternative Corrosion Resistant Metals

- Metals not listed in Appendix 1:
  - Types 302 and 400 series SS can be used when permitted by specific equipment 3-A Sanitary Standards or 3-A Accepted Practices
  - Alternative metals can be used if they pass the ASTM G31 *Laboratory Immersion Corrosion Testing of Metals*

Other Metals

METAL	APPLICATION
Aluminum	Limited application in 3-A Standards
Brass/Bronze	Not acceptable for product contact surfaces in 3-A applications
Copper	Not acceptable in 3-A applications

Non-Metals

- Must meet FDA requirements
- Must not chip, crack, or have crevices

NON-METALS

- Plastic
- Elastomer
- Carbon & Ceramic
- Adhesives / Bonding Agents

Plastic Failures

Mechanical Failure	• Impact crack • Overpressure pipe crack • Bending sagging • Deformation
Thermal Failure	• Extreme heat – melting, twisting burning • Extreme cold – brittle cracking
Chemical Failure	• Solvents • Ozone
Environmental Failure	• Heat • Pollution • UV rays

Photos of Plastic Failures

Partial List of Common Food Grade Plastics

- Acetal
- Nylon
- Polyethylene
- Polypropylene
- PTFE – Polytetrafluorethylene
- UHMW – Ultra-High-Molecular-Weight Polyethylene
- Peek – Polyether ether ketone
- PVDF – Polyether ether ketone
- Polysulfone
- PFA – PerFluoroAlkoxy

How to Select and Obtain Approval of Plastics

- Title 21 of the CFR, Parts 170-199
- Prior Sanction Letter
- GRAS (Generally Recognized as Safe)
- TOR (Threshold of Regulation) exemption request
- Food Contact Surface Notification Section 409(h)(2)(C)
- Letter of No Objection

FDA

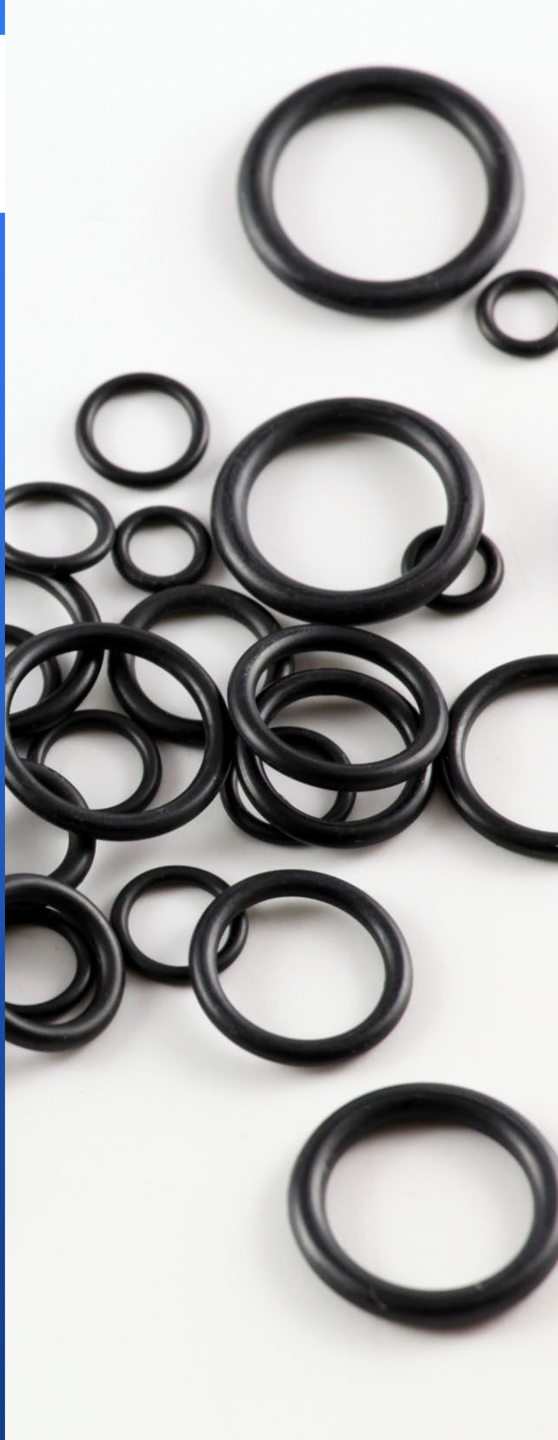
Question 4 - Test your knowledge?

Which non-stainless metal is acceptable in some 3-A standards and practices?

- **A.** Copper
- **B.** Brass
- **C.** Aluminum
- **D.** Bronze

Partial List of Common Food Grade Elastomers

- → EPDM
- → Fluorocarbon Rubber
- → Neoprene
- → Nitrile (NBR) – Buna N
- → Silicone



Elastomer Failures Causing Hygienic Risks

- Compression Set
- Chemical degradation and erosion
- Swelling
- Gap extrusion
- Ozonolysis and oxidation
- Heat ageing
- Over compression
- High friction
- Explosion compression
- Tears / crevices

Rubber Failure: Compression Set

- Poor resistance to compression set leads to permanent deformation:
  - Leakage and cross-contamination
  - Reduced cleanability due to reduced compression between gasket and housing (crevice)

Credit: Gabe Miller

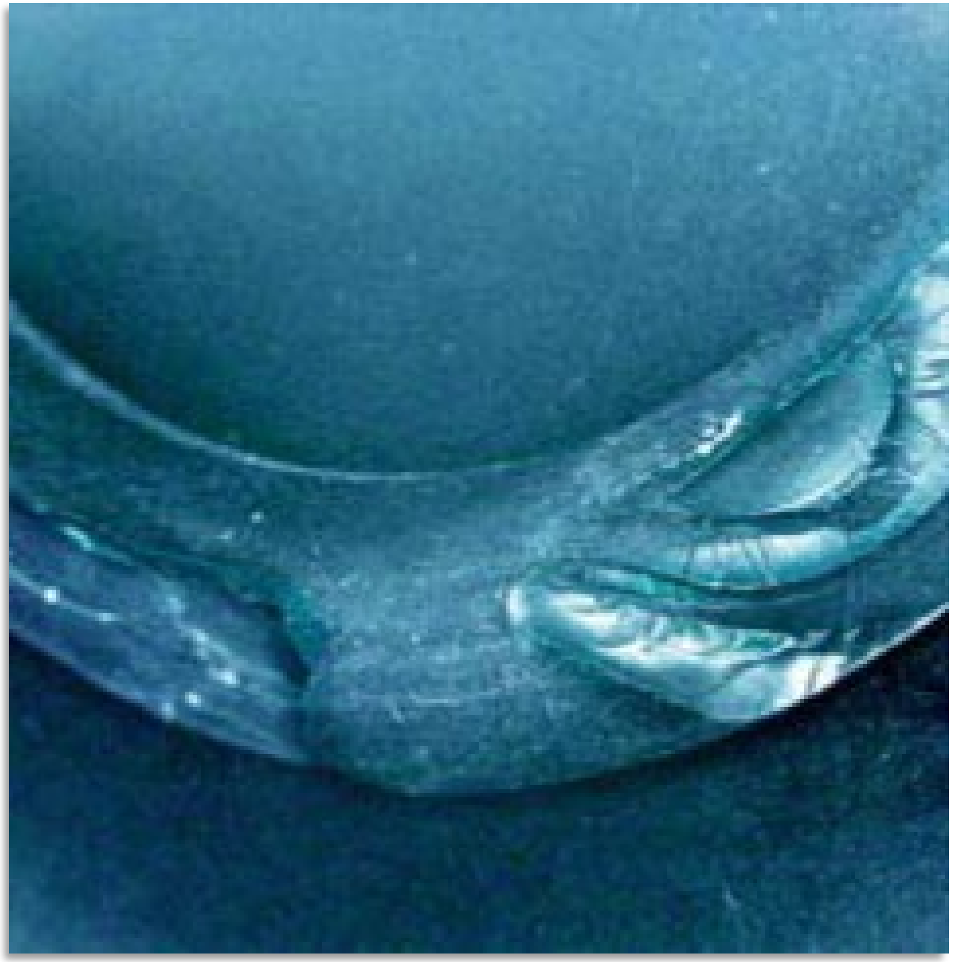
Rubber Failure: Chemical Degradation and Erosion

- Wrong selection of rubber can cause:
  - Accelerated degradation of polymer and change of the surface
  - Extraction of ingredients by which the bulk properties will change
- Which will eventually lead to:
  - Contamination of product
  - Leakage and cross-contamination
  - Reduced cleanability

Credit: Anders G. Christensen, AVK GUMMI A/S

Rubber Failure: Swelling

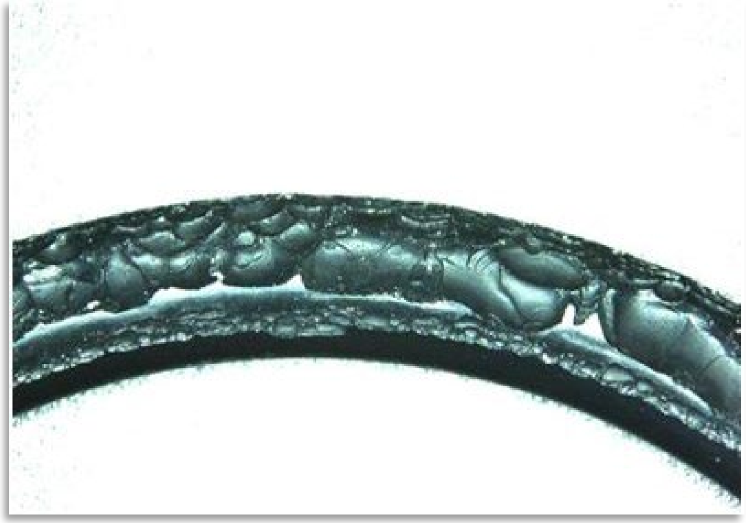
- Wrong selection of rubber can cause swelling, due to high solubility (eg. EPDM and high fat concentration)
- This will eventually lead to:
  - Functional error
  - Leakage and cross-contamination
  - Contamination of product due to tear



Credit: Anders G. Christensen, AVK GUMMI A/S

Rubber Failure: Gap Extrusion

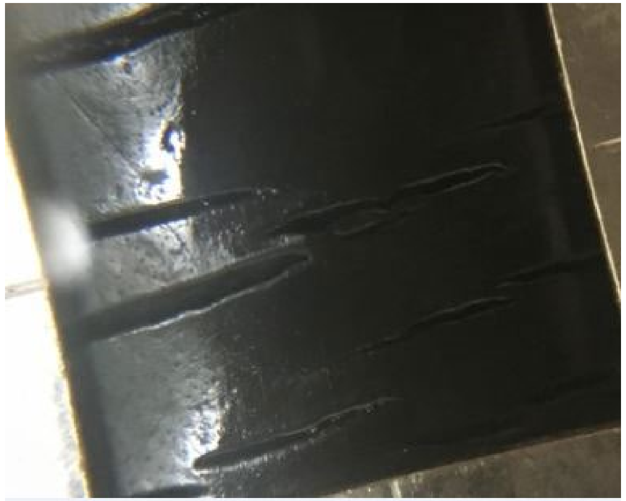
- Partially related to swelling and temperature increase, but also to pressure dynamics
- Reduced cleanability
- Risk of gasket debris in product
- Leakage and cross-contamination



Credit: Anders G. Christensen, AVK GUMMI A/S

Rubber Failure: Ozonolysis and Oxidation

- Polymer scission causing brittleness, cracking and loss of strength
  - Reduced cleanability
  - Risk of gasket debris in product
  - Leakage and cross-contamination



Rubber Failure: Heat Ageing

- Polymer degradation and loss of functional ingredients causing brittleness, loss of strength and elongation at break
  - Tear -> Gasket debris in product
  - Loss of volume -> Leakage
  - Loss of elasticity -> Leakage

Credit: Anders G. Christensen, AVK GUMMI A/S

Rubber Failure: Over Compression

- Crushing due to local overstressing of material
  - Reduced cleanability
  - Risk of gasket debris in product
  - Leakage and cross-contamination

Credit: Anders G. Christensen, AVK GUMMI A/S

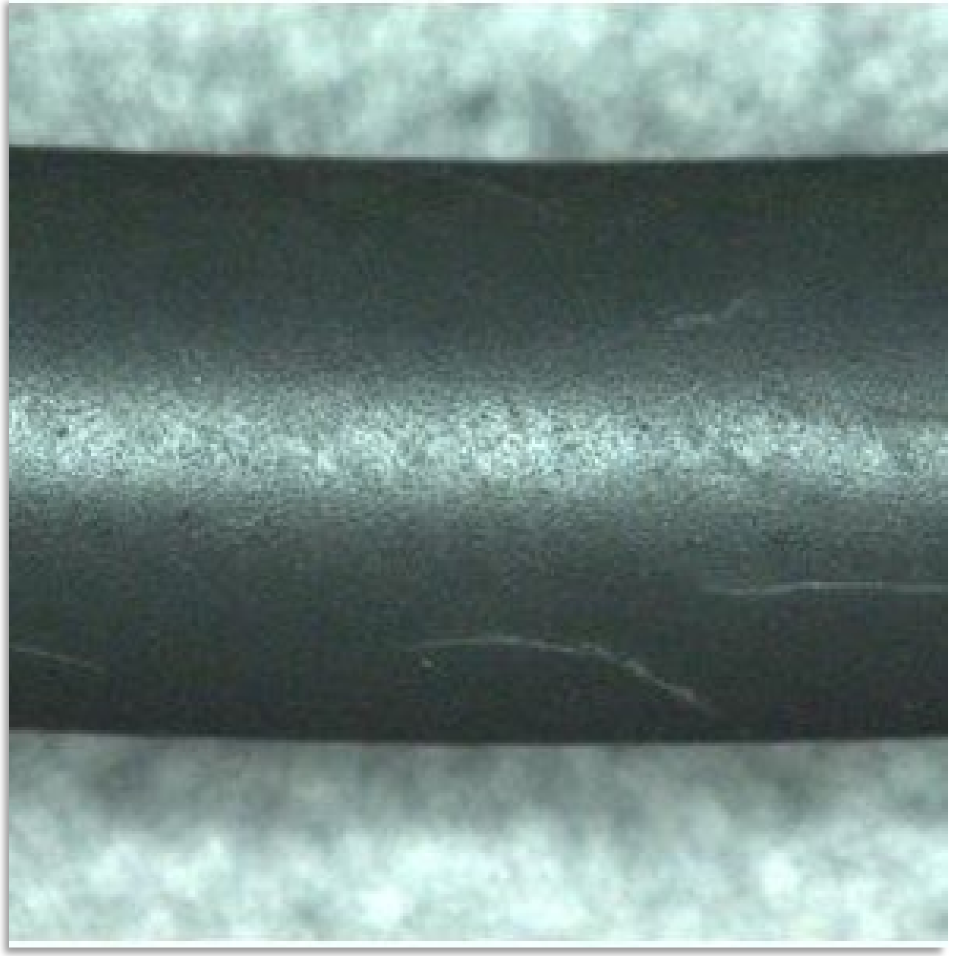
Rubber Failure: High Friction

- Frictional forces may exceed the shear resistance of the elastomer seal and cause surface damage:
  - Reduced cleanability
  - Risk of gasket debris in product
  - Leakage and cross-contamination

Credit: Anders G. Christensen, AVK GUMMI A/S

Rubber Failure: Explosive Decompression

- Sudden pressure drop can cause deep cracks in the gasket, as gas is trying to escape:
  - Leakage and cross-contamination
  - Reduced cleanability
  - Risk of gasket debris in product



Credit: Anders G. Christensen, AVK GUMMI A/S

Question 5 - Test your knowledge?

In addition to mechanical failure plastics can fail by which of the following:

- **A.** Thermal failure
- **B.** Environmental Failure
- **C.** Chemical Failure
- **D.** All of the above

Material Surface Finishes

- At least a smooth as 32 µin Ra (0.8 µm)*
- Free of pits, folds, cracks, crevices,
- 2B finish is generally acceptable
- *Carbon, ceramic, and plastic at least a smooth as 63 µin Ra (1.6 µm)

Metal Raw Material – Pre-Fabrication Surface Finishes

Metal Sheets, Bars, and Plates

- Cold-rolled 2B finish – typically meets the surface finish requirements for PCS
- Hot-rolled bars/plates – typically do not meet surface finish requirements for PCS
- Metal supplier can typically grind and polish to PCS surface requirement prior to shipment

Process Piping: Tube, Elbows, Tee, Valves, other Fittings

- Available with unfinished inside and outside surfaces
- Available with 20 to 32 µin (0.5 to 0.8 µm) Ra mechanical polish
- Available with 15 µin (0.38µm) Ra mechanical and electropolished surface

Castings

- Typically do not meet PCS requirements and need additional finishing

Cast Finish Exceeds PCS Specification

Elastomer Pre-Fabrication Surface Finishes

- Elastomers
  - Only as smooth as molding surfaces
  - Need to specify PCS requirements
  - Free of pits, blisters, cracks, crevices
  - Mold parting lines need to be smooth
  - No method to field improve surface finish after delivery

Plastics Pre-fabrication Surface Finishes

- Many sheet plastics are smooth enough in their prefabricated state to meet PCS requirements, except cut-off ends
- Molded plastics are only as smooth as molding surfaces
- Free of pits, blisters, cracks, crevices, or laminations
- Mold parting lines needs to be smooth
- Surfaces can be machined and sanded in field to improve surface finish

Processes Affecting Post-Fabrication Surface Finishes

Metals

- Handling damage
- Cutting and sawing
- Machining with mill or lathe
- Welding
- Brazing and soldering
- Grinding and polishing
- Pickling, electropolishing, and passivation

Plastics

- Handling damage
- Cutting and sawing
- Machining with mill or lathe
- Sanding and polishing

Machining Marks Added Roughness

Surface Hardening Treatments

Thermal

- *Surface Hardening*
  Laser
- *Electron Beam*

Diffusion:

- *Carburizing*
- *Nitriding*

Ion Implantation

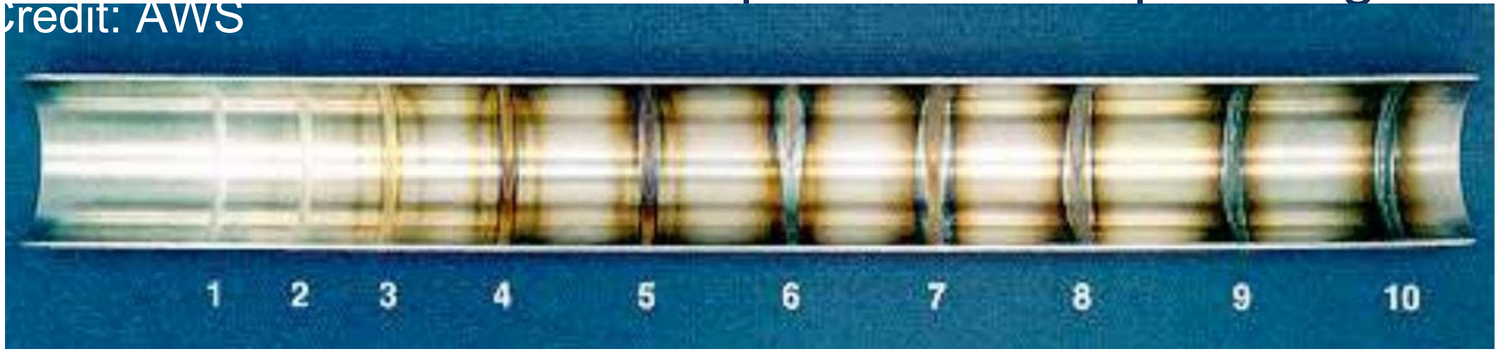
Surface Finish: PCS Specification

- At least a smooth as 32 µin Ra (0.8 µm)
- Including welded, soldered, and brazed joints
- Free of pits, folds, cracks, crevices, and misalignments
- 2B finish is generally acceptable
- Carbon, ceramic, and plastic at least a smooth as 63 µin Ra (1.6 µm)

PCS Finish: Product Pipelines

- Manual and orbital gas purged tube welds
- Material is at least a smooth as 32 µin Ra (0.8 µm)
- Interior weld does not need to be ground and polished for CIP applications
- Full penetration welds: free of pits, folds, cracks, crevices, and misalignments
- Tubing welds:
  - Meets criteria of AWS D18.1
  - Internal color meets the criteria of the AWS D18.2
  - Colors above 3 are not acceptable without polishing

Credit: AWS



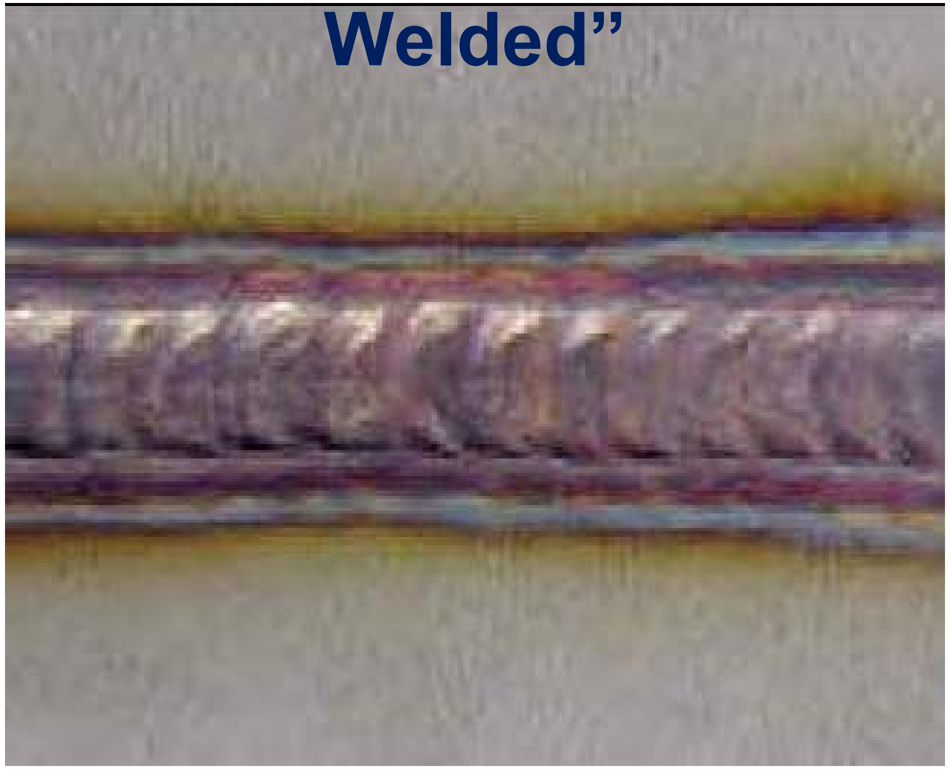
Surface Finish: NPCS

- Relatively smooth surfaces
- Relatively free of pockets and crevices
- Welds are not required to be ground or polished
- Blasting or other surface treatments that reduce surface finish of the base material should not be performed

2B Tubing Finish – caution!

Weld Ground Finishes

WF-1 “As Welded”

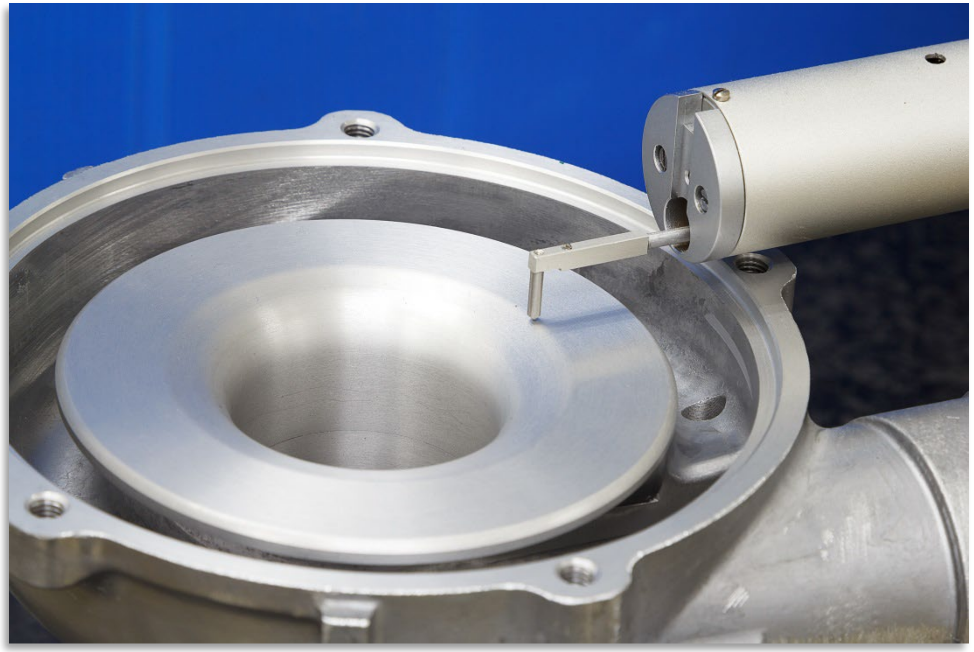


WF-7 “Ground Flush”

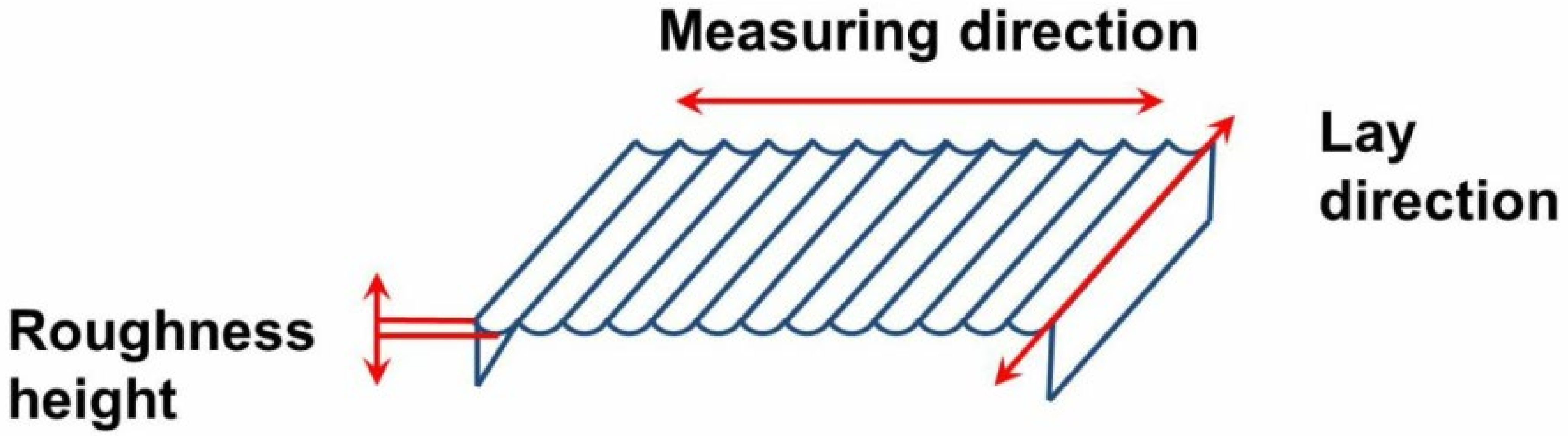
Stripe Grinding Weld

Surface Roughness Measurement

- Specify on drawings, specifications, and proposals
- Measure with profilometer
- Measure across the grain
- Optical comparators



Measurement with Profilometer



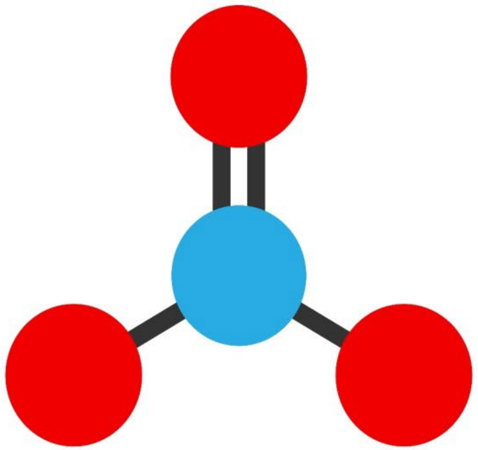
Question 6 - Test your knowledge?

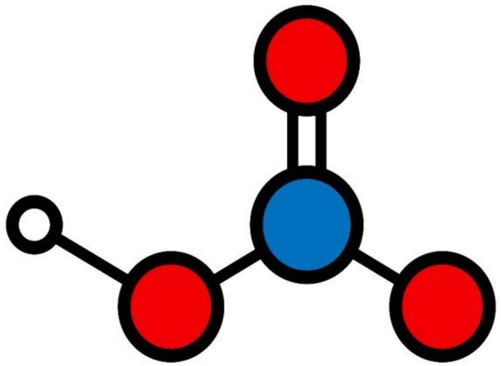
According to 3-A standards a product contact surface (PSC) on stainless steel needs to be at least as smooth as ____________________ measured with a profilometer?

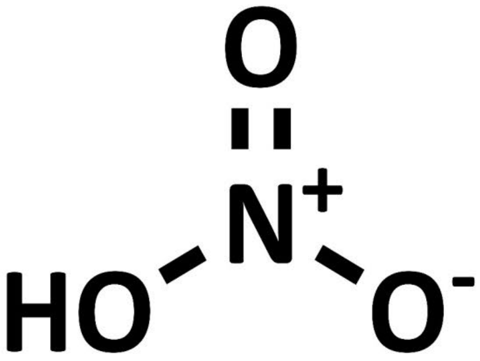
- **A.** 20 µin Ra (0.5 µm)
- **B.** #4 dairy finish
- **C.** 32 µin Ra (0.8 µm)
- **D.** 180 Grit

Chemical Treatments

- **Electropolishing**
  - Reverse plating – removes metal to improve surface finish
- **Passivation**
  - Chemical process to restore chromium and nickel oxide layer on stainless steel,
  - Removes iron contamination from manufacturing process
  - Passivate after field renovations
- **Pickling**
  - Chemical treatment to remove surface impurities such as stains, grease, and rust







Passivation Process

Clean

- all surfaces with detergent

Rinse

- all surfaces with water

Treat

- all surfaces with hot acid solution

Rinse

- all surfaces with water

Air Dry

- and allow the corrosion-resistant passive oxide layer to form

Summary

- All materials must be selected to assure that hygienic design is maintained for the life of the equipment
- Surface finishes must meet hygienic design requirements and maintained for the life of the equipment
- Written Material Certifications must be maintained on file

Live Q & A Session