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SMART HEALTHCARE ENGINEERING

2023-1-RO01-KA220-HED-000159985

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Stainless steel in healthcare facilities

- Alexandru Pascu

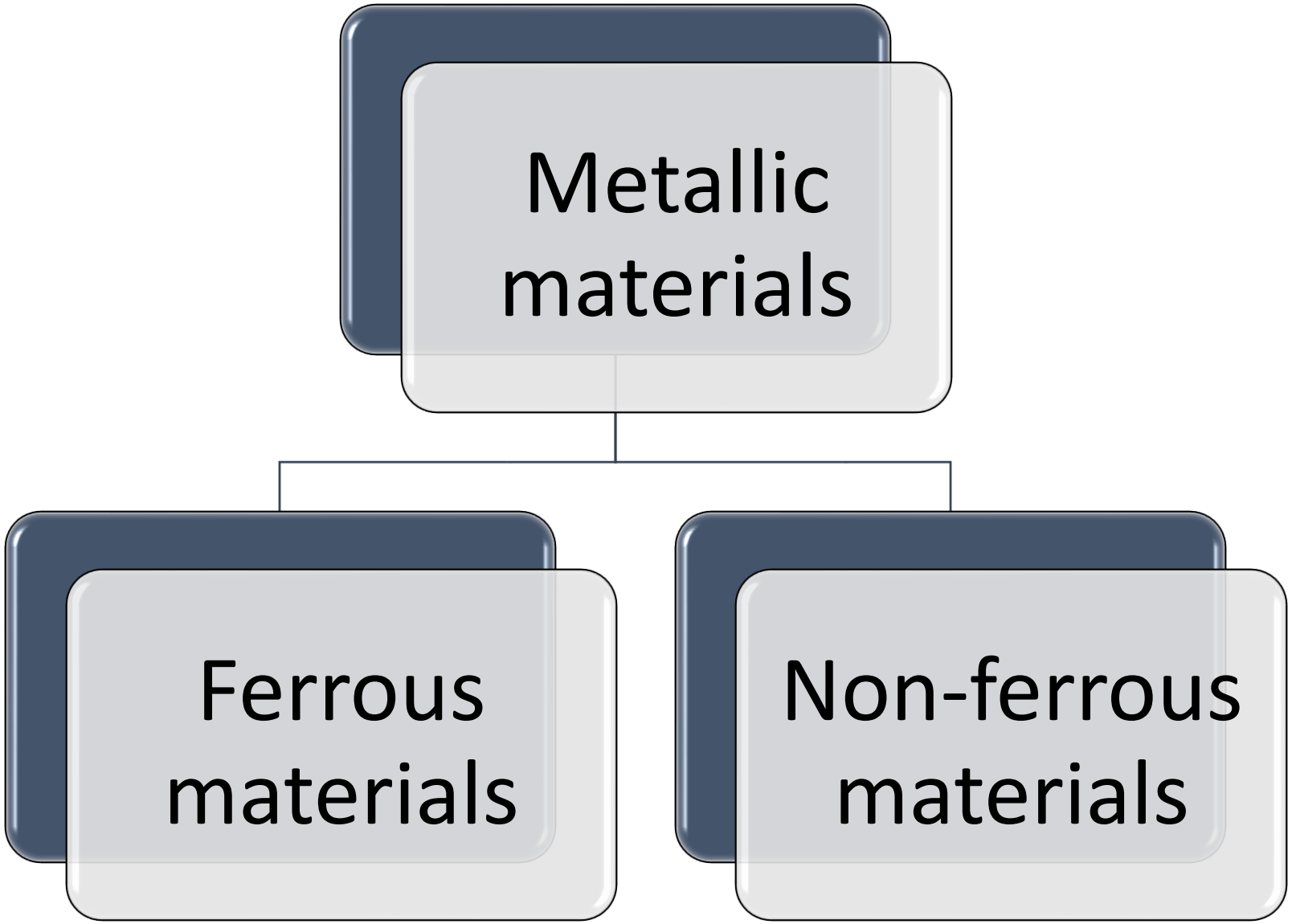
Universitatea Transilvania din Brașov

- Introduction
- Carbon steel vs. Stainless steel
- Properties of stainless steel in healthcare environments
  - Stainless steel composition and characteristics
  - Benefits: corrosion resistance, durability, and hygiene
  - Comparison with other materials used in healthcare
- Application of SS in hospital facilities : Pipes
- Medical gas pipeline
    - EN ISO 7396-1: Medical Gas Pipeline Systems Standard vs Industrial Standards (e.g., ISO 8573)
- Stainless steel welding

Iron ?

Steels ?

Alloys ?



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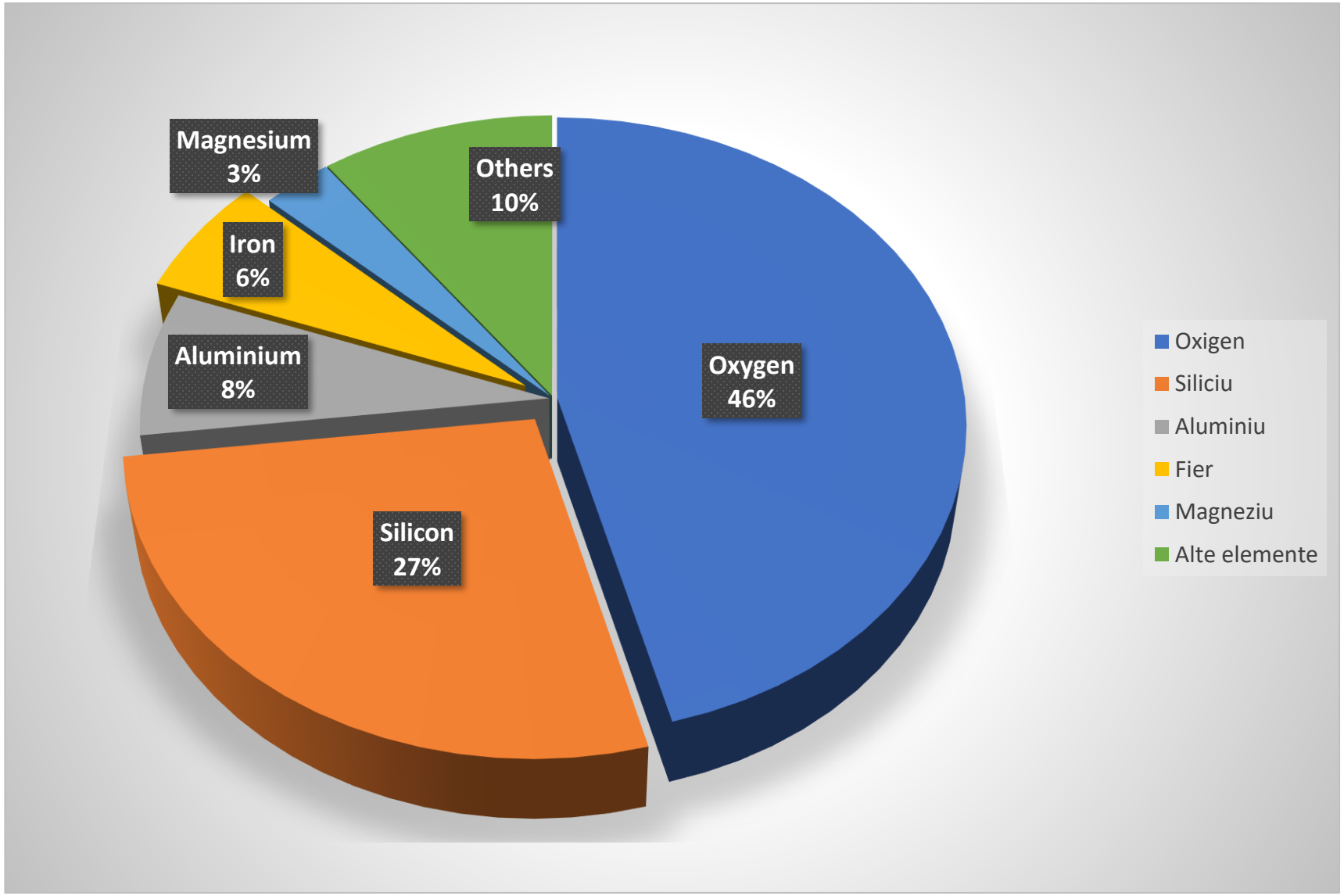
Elements distribution in earth's crust



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Energy for elaboration

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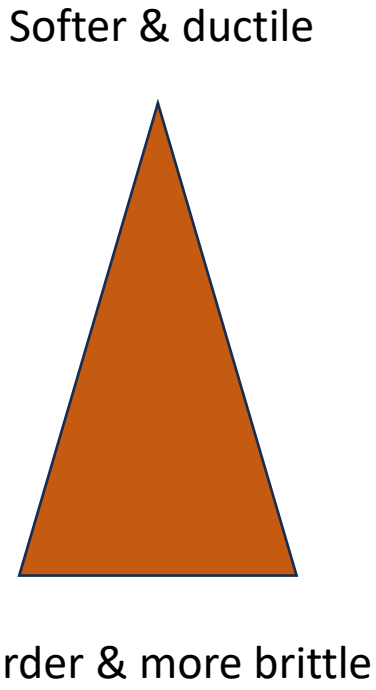
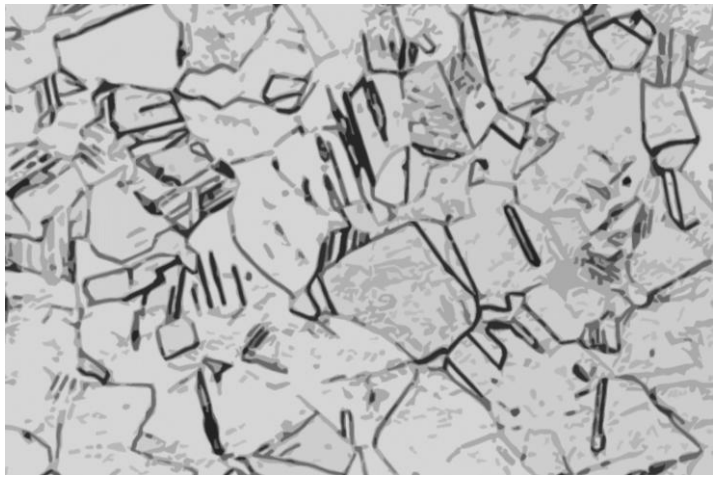
Steels

Low carbon steel (< 0.3 %)
Medium carbon steel (0.3% to 0.6% carbon content)
High carbon steel (> 0.6 %)

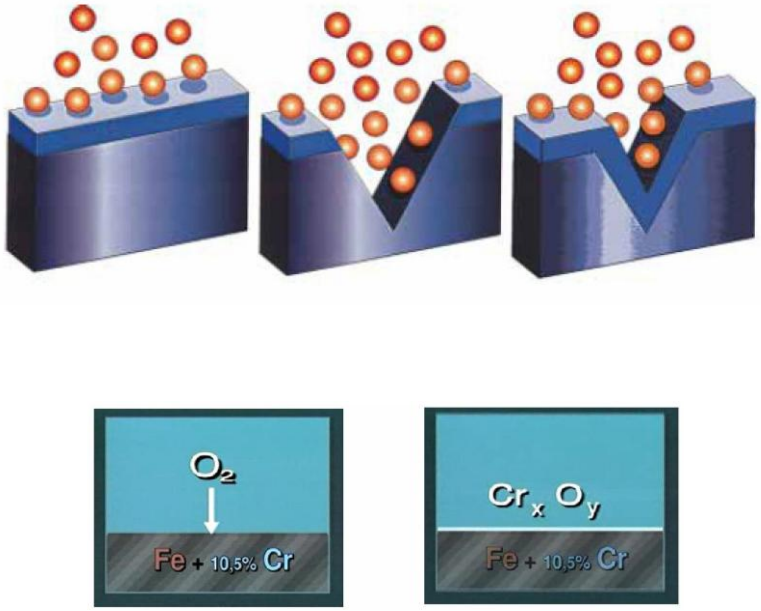




Stainless steel ?

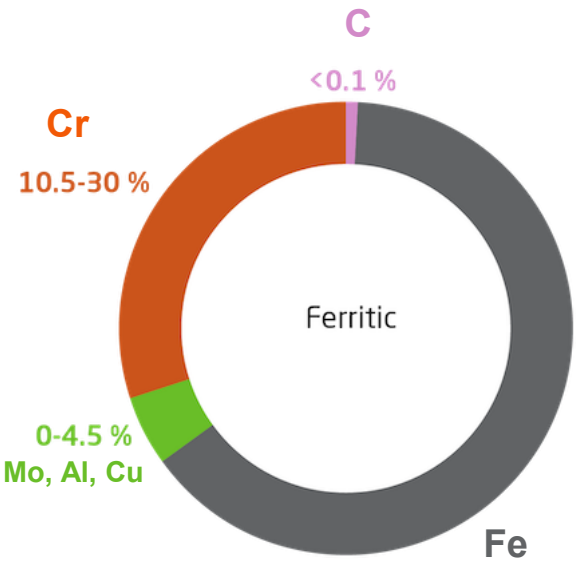
Min 10.5% Cr

Chromium
≥ 10.5%
Iron
Carbon
≤ 1.2%
Other
elements

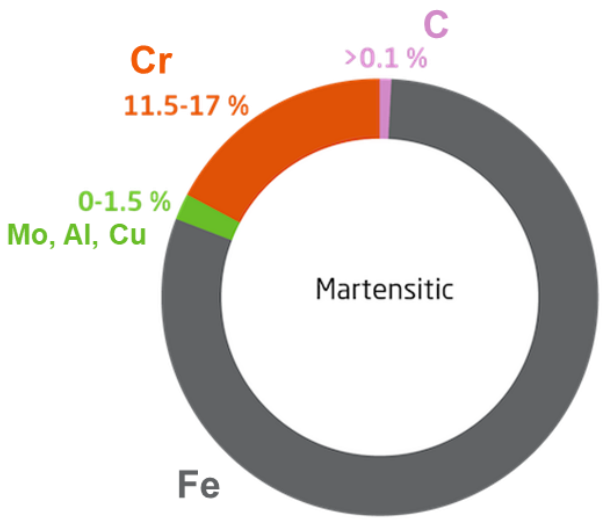

O2
Fe + 10,5% Cr
Cr x O y
Fe + 10,5% Cr

5 MAIN GRADES

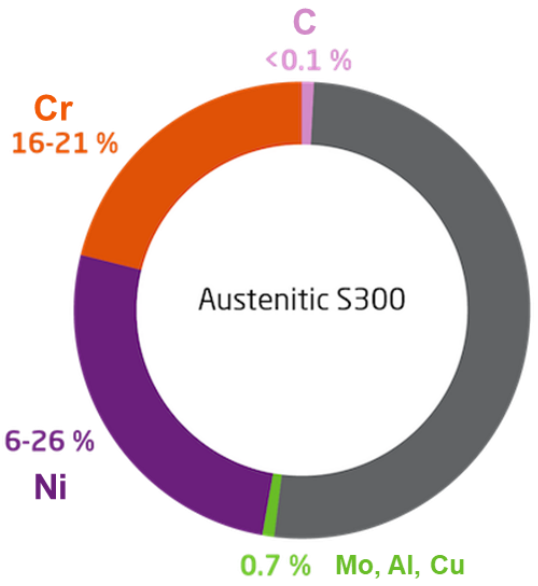
Min 10.5% Cr



Body-Centered Cubic (BCC)



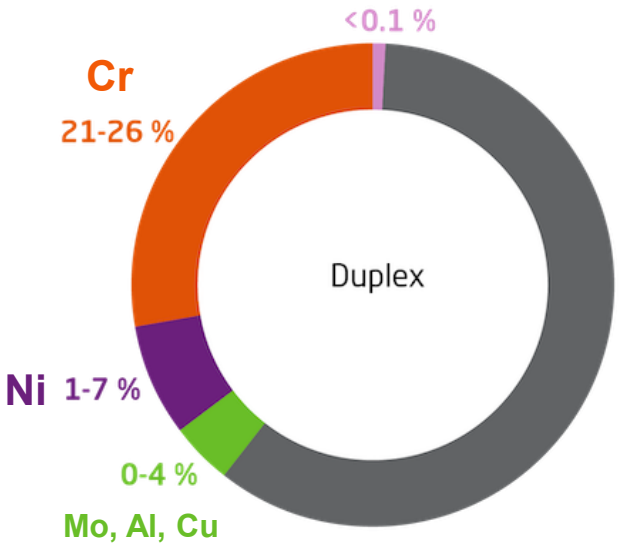
Body-Centered Tetragonal (BCT)

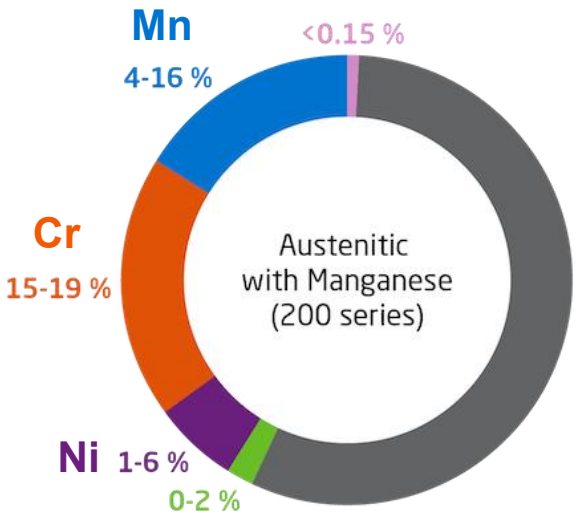


Face-Centered Cubic (FCC)

5 MAIN GRADES

Min 10.5% Cr





More details about the structure on next Thursday !

Stainless steel for hospitals ?

Stainless steel in hospitals

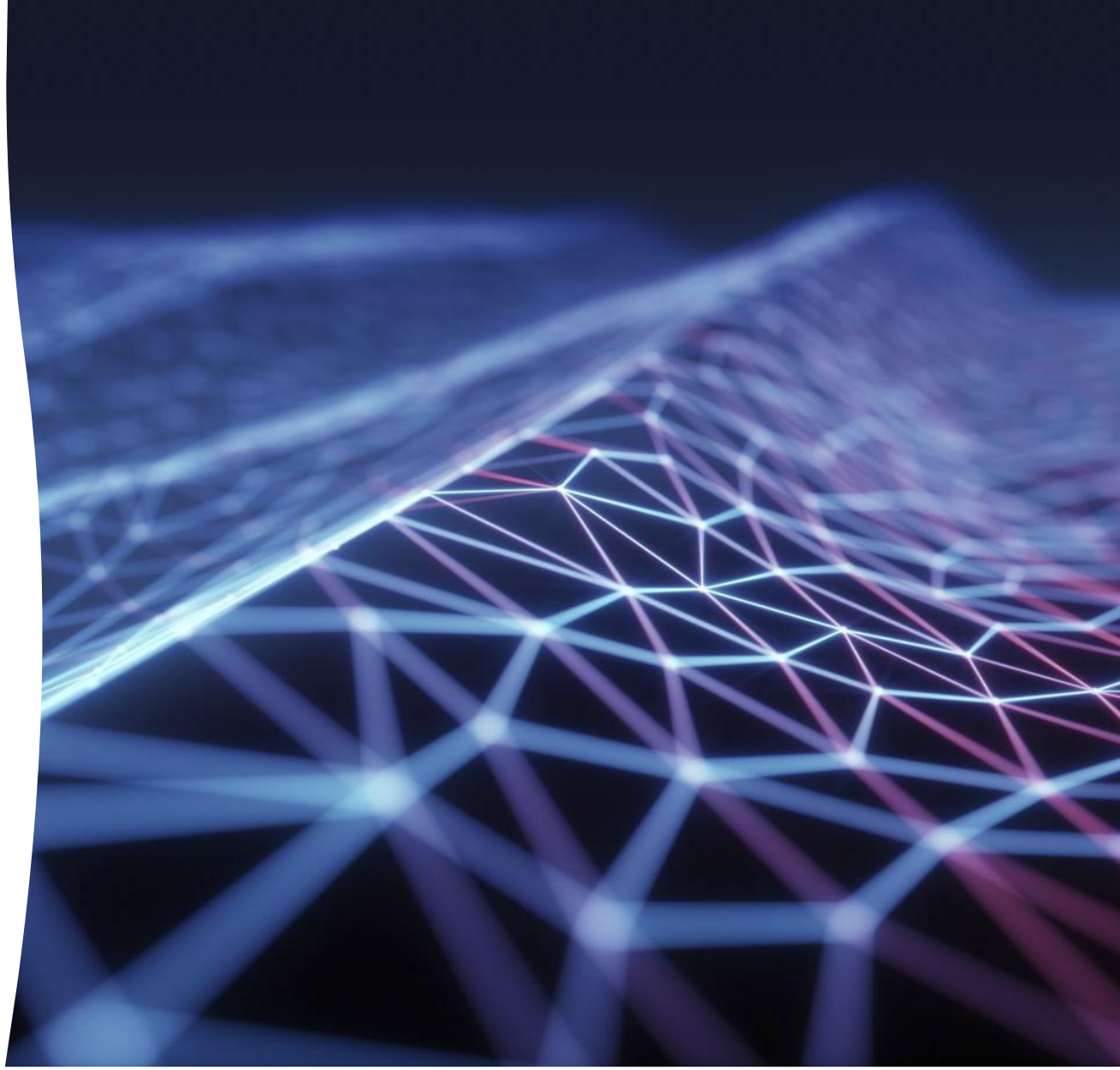
1. Corrosion resistance: Exceptional resistance to corrosion.

2. Mechanical strength and durability: Stainless steel exhibits high tensile strength and can endure the wear and tear of daily use in a hospital setting,.

3. Hygienic properties: Smooth and non-porous surface of stainless steel prevents the accumulation of dirt, bacteria and other pathogens.

4. Biocompatibility: Stainless steel, particularly certain grades like 316L, is biocompatible, meaning it is not harmful or toxic to living tissue.

5. Thermal conductivity and stability: Stainless steel is capable to distribute heat evenly.



Stainless steel for hospitals ?

- **Heaters and boilers | Grade :** 316 and 316L Stainless Steel. Excellent resistance to high temperatures and corrosive environments, ensuring long-term performance and safety in heating applications.

- **Plumbing/pipeline systems | Grade :** 304 Stainless Steel. Grade 304 provides sufficient corrosion resistance for water and waste systems, along with ease of installation and maintenance.

- **Medical gas piping | Grade :** 316 Stainless Steel. Due to the high purity and corrosion resistance of 316 stainless steel may be used for transport of medical gases.

- **Sterilization equipment | Grade :** 316L Stainless Steel. The low-carbon content and high corrosion resistance of 316L make it ideal for equipment that undergoes frequent sterilization cycles. Also is has an increased weldability.

- **HVAC systems | Grade :** 316L Stainless Steel. Has excellent thermal conductivity and resistance to corrosion make 316L being suitable for heat exchangers and other HVAC components.

- **Structural components | Grade :** 304 Stainless Steel. Grade 304 has a good strength and durability being ideal for structural applications.

- **Food service and kitchen appliance | Grade :** 430 Stainless Steel. Grade 430 offers good corrosion resistance at a lower cost, suitable for food preparation and storage areas where hygiene is critical.

Stainless steel for hospitals ?

Essentially, we have 4 grade of SS that are used in hospital facilities

AISI 304 , AISI 316, AISI 316 L and AISI 430

Stainless steel for hospitals ?

Chemical composition

Element	S355 (%)	AISI 304 (%)	AISI 316 (%)	AISI 316L (%)	AISI 430 (%)
Carbon (C)	≤ 0.23	≤ 0.08	≤ 0.08	≤ 0.03	≤ 0.12
Chromium (Cr)	0.3 max	18.0 - 20.0	16.0 - 18.0	16.0 - 18.0	16.0 - 18.0
Nickel (Ni)	-	8.0 - 10.5	10.0 - 14.0	10.0 - 14.0	≤ 0.75
Manganese (Mn)	≤ 1.6	≤ 2.0	≤ 2.0	≤ 2.0	≤ 1.0
Silicon (Si)	≤ 0.55	≤ 0.75	≤ 0.75	≤ 0.75	≤ 1.0
Phosphorus (P)	≤ 0.045	≤ 0.045	≤ 0.045	≤ 0.045	≤ 0.04
Sulfur (S)	≤ 0.045	≤ 0.030	≤ 0.030	≤ 0.030	≤ 0.03
Molybdenum (Mo)	-	-	2.0 - 3.0	2.0 - 3.0	-
Nitrogen (N)	-	≤ 0.10	≤ 0.10	≤ 0.10	-
Copper (Cu)	≤ 0.55	-	-	-	-
Iron (Fe)	Balance	Balance	Balance	Balance	Balance

Stainless steel for hospitals ?

Tensile vs. Yield strength

Maximum stress – breaking point

Maximum stress applied before permanent deformation

Stainless steel for hospitals ?

Mechanical behaviour

Property	S355	AISI 304	AISI 316	AISI 316L	AISI 430
Tensile Strength (MPa)	450 - 630	515 - 720	515 - 690	485 - 620	450 - 700
Yield Strength (MPa)	≥ 355	205	205	170	275
Elongation at Break (%)	20 - 22	40	40	40	22
Hardness (Brinell)	146 - 187	123 - 201	123 - 220	123 - 190	150 - 183
Density (g/cm³)	7.85	7.93	7.99	7.99	7.70
Thermal Conductivity (W/m·K)	54	16.2	16.3	16.3	26

- **Grade 304 Stainless Steel**
  - **Properties:** Known for its excellent corrosion resistance, ease of fabrication, and good mechanical properties. It contains 18% chromium and 8% nickel.
  - **Applications:**
    - **Pipes and Plumbing Systems:** Grade 304 is used for plumbing systems due to its ability to withstand various chemical exposures and its non-reactivity with water.
    - **Structural Components:** Often used in structural supports and frameworks because of its strength and durability.
    - **Furnishings:** Used in sinks, countertops, and other surfaces that require frequent cleaning and sterilization.

- **Grade 316 Stainless Steel**
  - **Properties:** Contains 16% chromium, 10% nickel, and 2-3% molybdenum. The addition of molybdenum enhances its corrosion resistance, especially against chlorides and other industrial solvents.
  - **Applications:**
    - **Heating Systems and Boilers:** Grade 316 is preferred for heaters and boilers due to its superior resistance to high temperatures and corrosive environments.
    - **Medical Gas Systems:** Can be used in the piping for medical gases.
    - **Sterilization Equipment:** Ideal for autoclaves and other sterilization devices due to its ability to withstand repeated high-temperature cycles.

- **Grade 316L Stainless Steel**
  - **Properties:** A low-carbon version of 316 stainless steel, which offers improved weldability and reduces the risk of carbide precipitation during welding.
  - **Applications:**
    - **Surgical instruments and implants:** Due to its excellent biocompatibility and resistance to corrosion, 316L is used for surgical instruments, implants, and other medical devices.
    - **Heat exchangers:** Utilized in heat exchangers within HVAC systems in hospitals for efficient thermal management.

- **Grade 430 Stainless Steel**
  - **Properties:** A ferritic stainless steel containing 17% chromium. It is less expensive than 304 and 316 grades and has good resistance to corrosion and heat.
  - **Applications:**
    - **Interior decorative applications:** Used in areas where less corrosive conditions are present, such as wall panels and interior trims.
    - **Food service equipment:** Employed in the fabrication of food service carts, storage cabinets, and other equipment where hygiene is crucial.

Medical gases pipeline in Hospitals

Medical air

Natural or synthetic mixture of gases, mainly composed of oxygen and nitrogen in specified proportions, with defined limits for the concentration of contaminants, supplied by a medical gas pipeline system and intended for administration to patients.

Medical gas

Any gas or mixture of gases intended for administration to patients for anesthetic, therapeutic, diagnostic or prophylactic purposes or for surgical tool applications.

ISO 7396

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Stainless Steel ?

Copper

Medical gases pipeline in Hospitals

Medical gases pipeline in Hospitals

Copper

Antimicrobial Properties

•**Copper**: Copper has **natural antimicrobial properties**, which means it can inhibit the growth of bacteria and other pathogens on its surface.

•**Stainless Steel**: Stainless steel is also hygienic and easy to clean (316 grade), but it does **not have** the same inherent antimicrobial properties as copper.

Medical grade copper, which is phosphorous deoxidized non-arsenical copper.

The copper tubing/pipes should be made in accordance with EN 13348.

EN ISO 7396-1: Medical Gas Pipeline Systems - Part 1: Pipeline Systems for Compressed Medical Gases and Vacuum

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Medical gases pipeline in Hospitals

EN ISO 7396-1: Medical Gas Pipeline Systems - Part 1: Pipeline Systems for Compressed Medical Gases and Vacuum

The standard covers:

- Pipeline systems for compressed medical gases such as oxygen, nitrous oxide, medical air, carbon dioxide, and mixtures of these gases.
- Pipeline systems for vacuum and anaesthetic gas scavenging systems.
- Specification of materials, components, and system design requirements.
- Procedures for installation, testing, commissioning, and maintenance.

Feature/Aspect	EN ISO 7396-1	ISO 8573
Scope	Medical gas pipeline systems in healthcare	Compressed air purity classes for various applications
Application	Healthcare facilities	Industrial processes, pneumatic tools, medical devices
Focus	Delivery of medical gases	Purity classes: particles, water, oil content
Quality Requirements	Ensures gas purity and safety for patients	Specifies classes for air purity levels
Safety and Compliance	Patient safety and operational reliability	Ensures air quality meets specific standards
Maintenance and Testing	Regular maintenance and testing	Monitoring and testing air quality
Regulatory Emphasis	System integrity and leak detection	Compliance with purity classes
Testing Methods	Pressure testing, flow testing	Sampling, analysis techniques

Quality Requirements:

•**EN ISO 7396-1**: Emphasizes the purity and safety of medical gases, with requirements for cleanliness, corrosion resistance, and compatibility with medical applications. It ensures gases meet strict standards to prevent contamination and ensure patient safety.

•**ISO 8573**: Defines purity classes for compressed air based on particle size, water content, and oil content. It provides guidelines for monitoring and testing compressed air quality to ensure it meets the specific needs of different applications, including those requiring clean and dry air.

Hospitals Standards

Pipeline assembly

Inert gas filling

Stainless steel

Copper

Welding

Brazing

Welding

Welding is a joining process in which two (or more) parts (usually metallic) are coalesced at their contacting surfaces by application of heat and/or pressure.

Heat / Pressure- Melting the base materials- Solidifications

- Provides a permanent joint
- Usually, the most economical way to join parts in terms of material usage and fabrication costs
- Not restricted to a factory environment.

Brazing

- Joining process in which a filler metal is melted and distributed by capillary action between faying surfaces of metal parts being joined
  - No melting of base metals occurs
    - Only the filler melts
  - Filler metal T_m is greater than 450°C
  - But less than T_m of base metal(s) to be joined

Welding of stainless steel

More than 40 different types of welding processes have been developed so far and within them the recommended processes for fusion welding of stainless steel are:

TIG Welding

MMA Welding (Manual Metal Arc Welding)

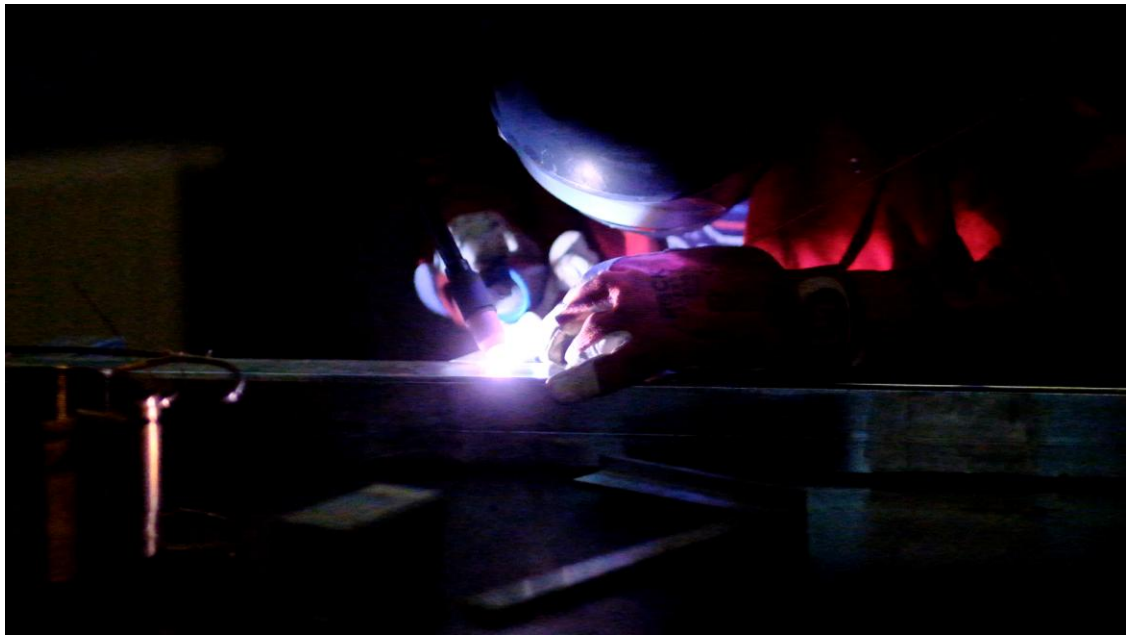
MIG welding (Metal inert Gas Welding)

Laser Welding

Welding Process
Gas Tungsten Arc Welding (GTAW/TIG)
Gas Metal Arc Welding (GMAW/MIG)
Shielded Metal Arc Welding (SMAW/Stick)
Flux-Cored Arc Welding (FCAW)
Submerged Arc Welding (SAW)
Plasma Arc Welding (PAW)
Laser Beam Welding (LBW)
Electron Beam Welding (EBW)
Resistance Spot Welding (RSW)
Resistance Seam Welding (RSEW)
Friction Stir Welding (FSW)
Stud Welding
Thermit Welding
Ultrasonic Welding
Explosive Welding

Welding of stainless steel

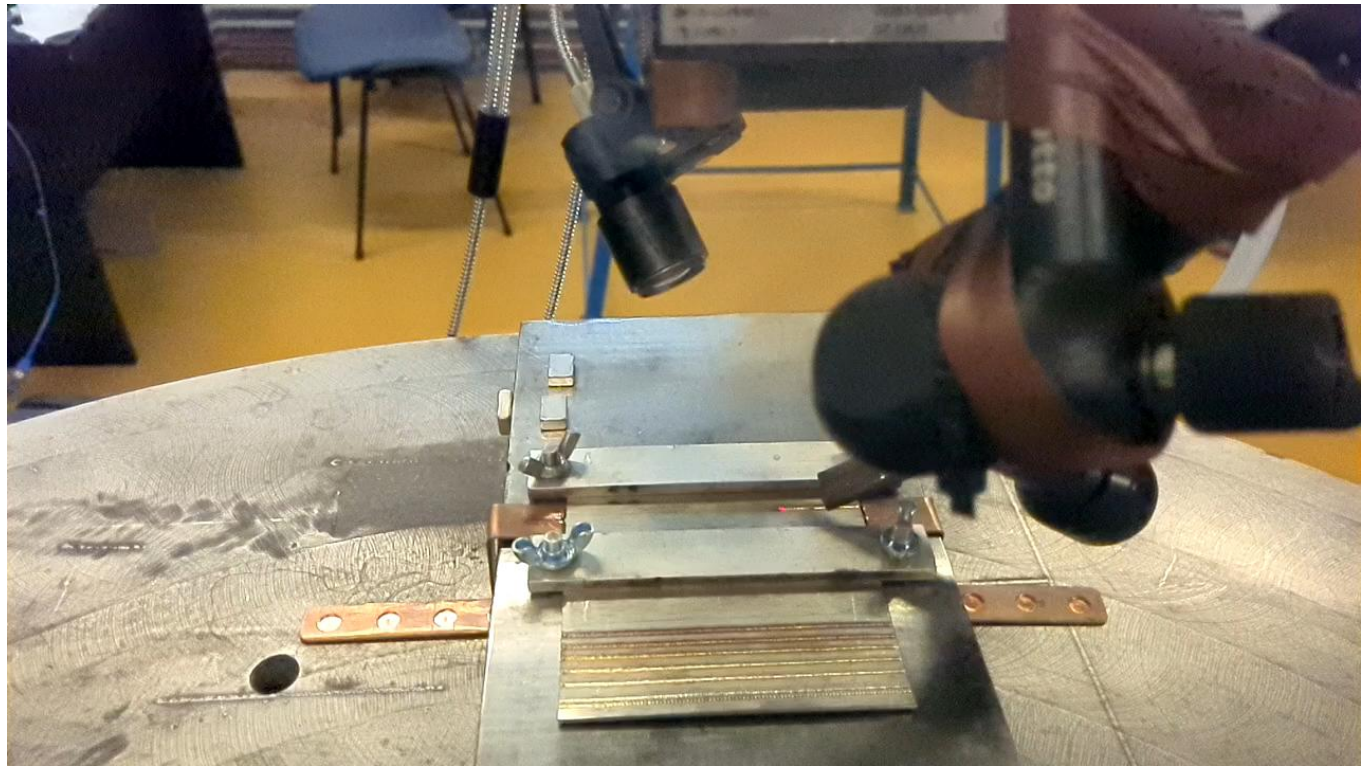
WIG	*Wolfram Inert Gas*
TIG	*Tungsten Inert Gas*
GTAW	Gas Tungsten Arc Welding
heliarc	*Heliu - Arc electric*



- Advantages:
  - High quality welds for suitable applications
  - No spatter because no filler metal through arc
  - Little or no post-weld cleaning because no flux
- Disadvantages:
  - Generally slower and more costly than consumable electrode arc welding processes

Laser welding of stainless steel

- Advantages:
  - High speed
  - Without filler material
  - Non contact process
  - Can be realized in a sterile environment (enclosure box)
  - Easy to automatize



Dependent on the surface reflectivity.

Welding of stainless steel

Welding process

Stainless steel grade

Parameters of the welding process (welding current, welding speed, laser power and so on)

Filler material type

Cleanness of the surface

Always should be verified the structure of the weld by using Schaeffler / Delong diagram

Welding of austenitic stainless steel

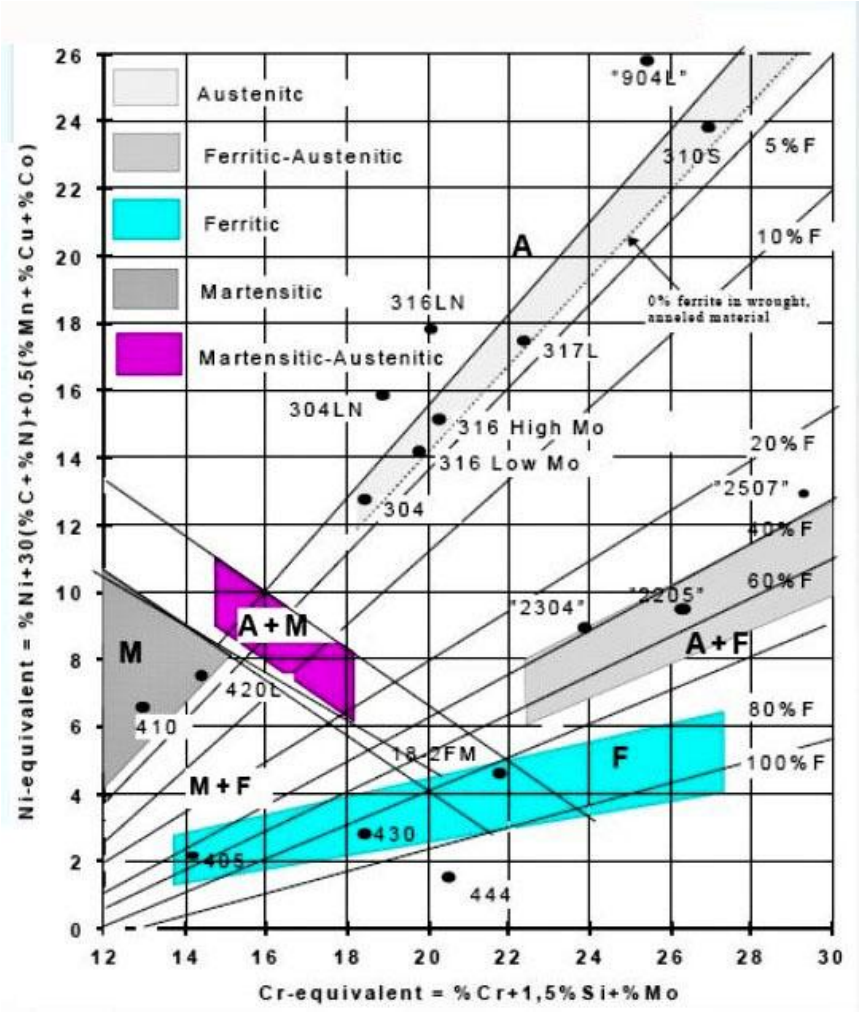
AUSTENITIC STAINLESS STEELS	
TYPE	Equivalent UNS
201	S20100
202	S20200
205	S20500
301	S30100
302	S30200
302B	S30215
303	S30300
303Se	S30323
304	S30400
304L	S30403
302HQ	S30430
304N	S30451
305	S30500
308	S30800
309	S30900
309S	S30908
310	S31000
310S	S31008

314	S31400
316	S31600
316L	S31603
316F	S31620
316N	S31651
317	S31700
317L	S31703
317LMN	S31726
321	S32100
330	NO8330
347	S34700
348	S34800
384	S38400

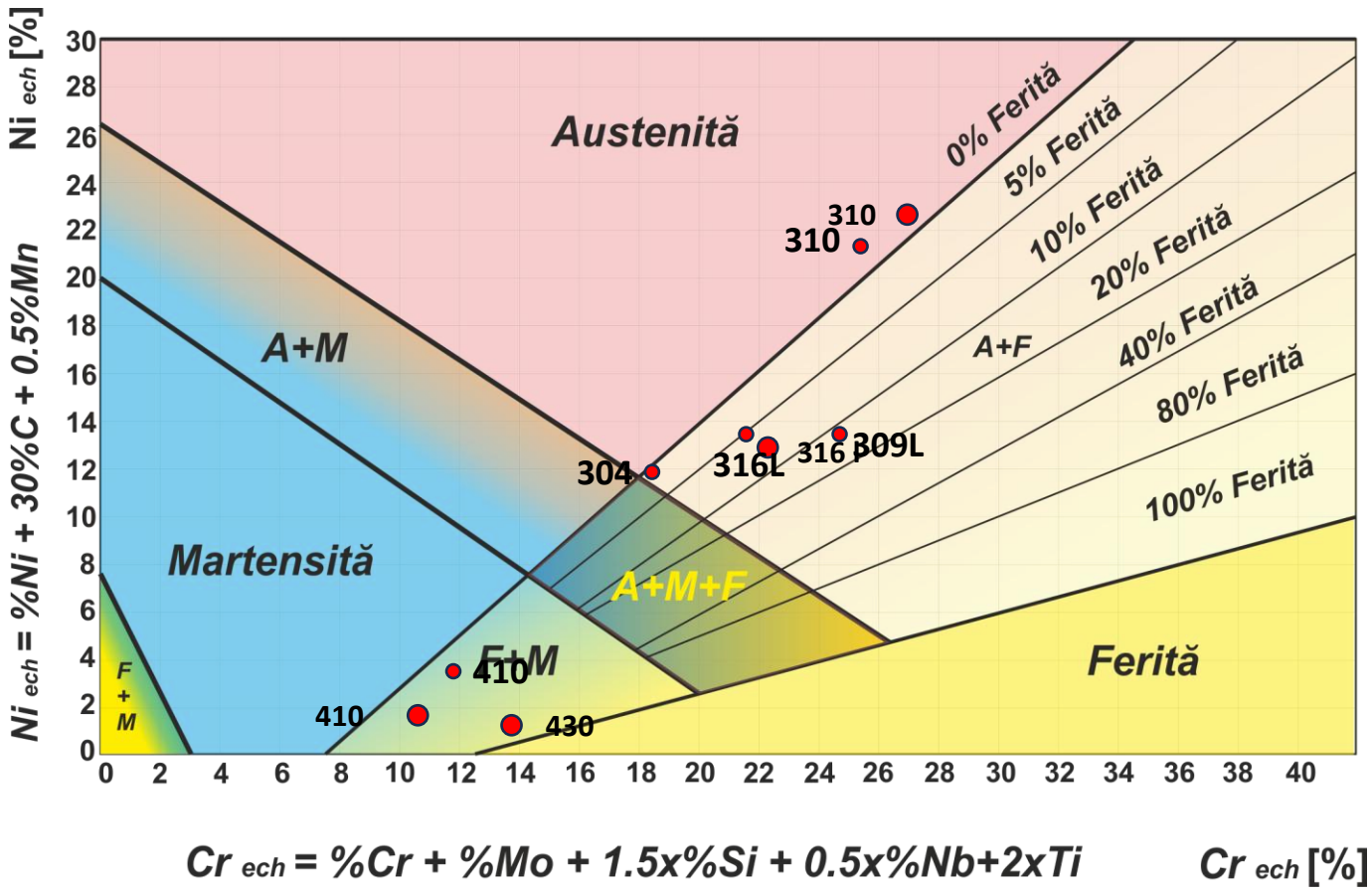
100 % austenitic

2 – 15 % Ferrite

Welding of stainless steel



The Schaeffler diagram is used to predict the phases (austenite, ferrite, martensite) in stainless steels based on their composition.



Schaeffler-Delong diagram

Case study. Welding of austenitic stainless steel medical grade

Welding of AISI 316 with AISI 304

Welding of austenitic stainless steel

Element	S355 (%)	AISI 304 (%)	AISI 316 (%)
Carbon (C)	≤ 0.23	≤ 0.08	≤ 0.08
Chromium (Cr)	0.3 max	18.0 - 20.0	16.0 - 18.0
Nickel (Ni)	-	8.0 - 10.5	10.0 - 14.0
Manganese (Mn)	≤ 1.6	≤ 2.0	≤ 2.0
Silicon (Si)	≤ 0.55	≤ 0.75	≤ 0.75
Phosphorus (P)	≤ 0.045	≤ 0.045	≤ 0.045
Sulfur (S)	≤ 0.045	≤ 0.030	≤ 0.030
Molybdenum (Mo)	-	-	2.0 - 3.0
Nitrogen (N)	-	≤ 0.10	≤ 0.10
Copper (Cu)	≤ 0.55	-	-
Iron (Fe)	Balance	Balance	Balance

Industrial standard

Medical and pharmaceutical grade

Welding of austenitic stainless steel

Stainless still have a **good weldability** and it is heavily used in industry for various applications.

Using stainless steel medical grade can rise challenges in term of materials compatibility and adjusting the welding parameters is mandatory.

Sulfur, selenium and phosphorus are sometimes added to stainless steels to make their machinability easier but reduces the corrosion resistance.

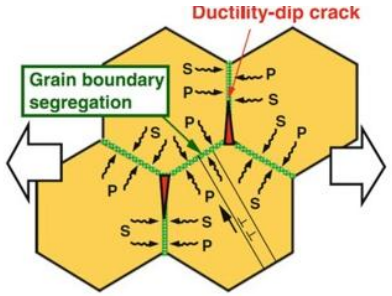
New standards impose a strict control of Sulphur content in stainless steel that are used in medical application (Orthopedic implants, Surgical instruments), which has high implications on the welding process.

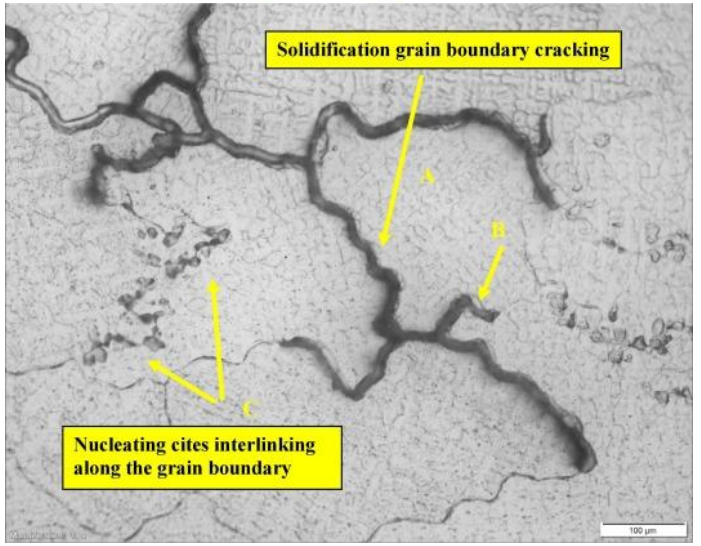
WHAY?

Welding of austenitic stainless steel

Sulfur and phosphorus tend to segregate during solidification, resulting in a thin liquid film of sulfur (such as low-melting phases like manganese sulfide or iron sulfide) remaining in the intergranular spaces after solidification begins. The stresses during solidification can cause intergranular fracture.

Liquid film cracking





https://doi.org/10.1016/j.engfailanal.2022.106488

Ferrite δ

Welding of austenitic stainless steel

Hot cracking
Liquid film cracking

S – 0.003 ... 0.030 %

Ferrite δ

1. Dissolve the S & P and prevent the formation of the liquid film at the interface of the grains.

2. The Ferrite δ increase the intergranular space and therefore the Sulphur can be distributed on a higher surface mitigating the formation of the liquid film.

Austenitic stainless steel

Ferrite δ

Hot cracking
Liquid film cracking

S – 0.003 ... 0.030 %

Max. 0.005% S

Min. 0.010% S

Higher melted bath

Low penetration

Low melted bath

High penetration

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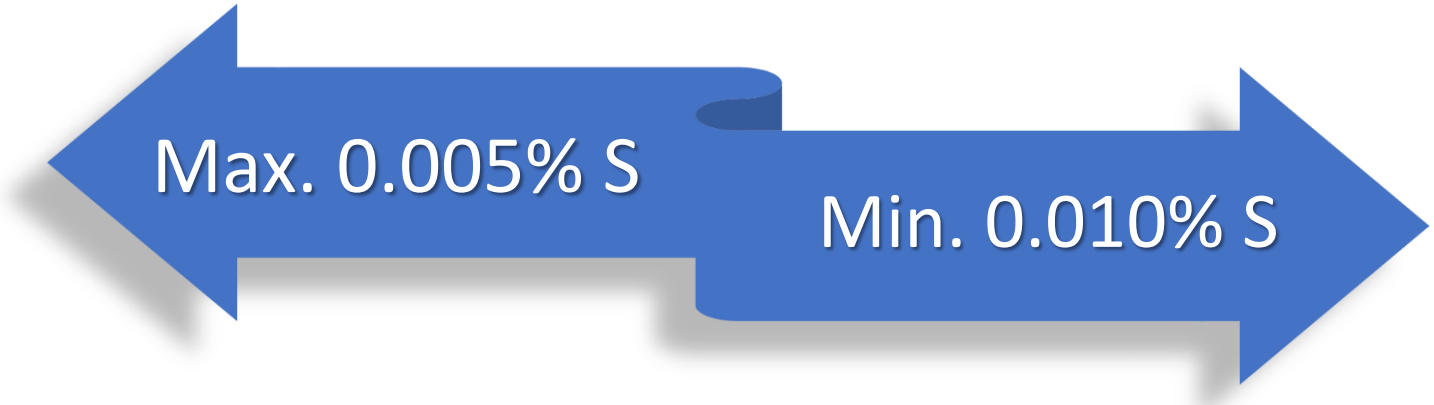
Welding of austenitic stainless steel

AISI 316



AISI 304

Automatized welding| orbital welding

Defects

Incomplete penetration

High penetration, root overmelting

2 Sets of parameters. Ones for low Sulphur content and ones for High sulfur content

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Advantages of welding of welding of stainless steel

Good weldability

Compatibility with a high range of welding processes.

Good compatibility with carbon steels (dissimilar welding)

Exhibits good performance in laser welding due to its low thermal conductivity.

Stainless steel maintains its resistance to corrosion and rust after the welding process.

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