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STAINLESS STEEL IN HEALTHCARE FACILITIES

Part 1

Class content material

This document is part of a training materials collection developed within the Erasmus+ project “Smart healthcare engineering”, SHEng, project No. 2023-1-RO01-KA220-HED-000159985.

The collection is intended for engineering students and professionals working in the healthcare sector. It covers technical subjects relevant to hospital infrastructure, equipment, materials and support services, helping readers understand how engineering contributes to safe patient care and the reliable operation of healthcare facilities.

These materials support classroom teaching and independent study. They should be used alongside the project handbook and the presentations, courses and other learning resources available on the project website. Each document addresses a specific subject, while the collection provides a broader understanding of the responsibilities and practical challenges of healthcare engineering.

The content is educational. Its application in practice requires consideration of the conditions of each healthcare facility, the applicable standards and the instructions provided by equipment manufacturers.

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SMART HEALTHCARE ENGINEERING

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STAINLESS STEEL IN HEALTHCARE FACILITIES

Materials, applications and maintenance

Introduction

Stainless steel is used in hospital furniture, instruments, equipment and utility systems. These applications place different demands on the material. A worktop needs a surface that can be cleaned repeatedly and a cutting instrument needs hardness. A welded pipe needs joints and resistance to the fluid it carries. **Selecting the same grade for every application is rarely justified.**

1. Material fundamentals

From iron to stainless steel

Steel is an iron-based alloy in which carbon influences the microstructure, mechanical properties and response to heat treatment. Carbon may be present in solid solution or combined in carbides, depending on the composition and processing conditions. In plain carbon steels, increasing the carbon content generally increases the hardness achievable through quenching, but may reduce ductility, toughness and weldability. The final properties also depend on grain size, the phases present and their distribution, which are affected by rolling, forming, welding and heat treatment. Steels with similar chemical compositions can therefore behave differently if their processing histories are different.

Stainless steels contain at least 10.5% chromium by mass, which allows a thin, adherent passive film enriched in chromium to form on the surface, as illustrated in fig. 1. This film is generally only a few nanometres thick and contains oxides and hydroxides, with a chromium rich inner region that limits metal dissolution. Its protective action differs from that of the rust commonly formed on unprotected carbon steel, which is usually porous and does not provide a continuous barrier against further corrosion. Stainless steel corrosion resistance therefore depends on both the alloy composition and the stability of this surface film in the service environment.

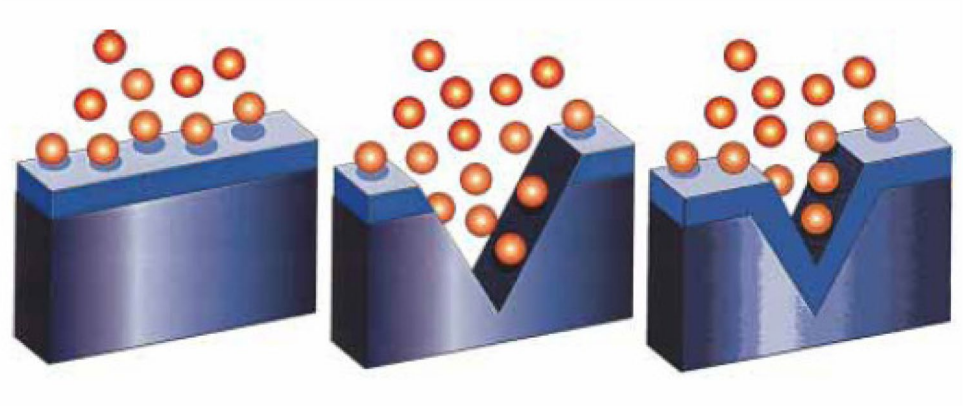

Figure 1. Formation of the passive film [1]

If the passive film is locally damaged, it can reform when the surrounding conditions support repassivation, commonly through exposure to oxygen in air or dissolved in water. This process restores surface protection but does not replace metal already lost through corrosion or repair cracks and other structural defects. Chlorides can destabilise the film and initiate pitting, while deposits and narrow crevices can restrict solution exchange and create local conditions that favour continued attack. Welding can also reduce corrosion resistance when inadequate shielding produces heat tint and a chromium-depleted region beneath the oxide scale.

What the alloying elements do

The alloying elements in stainless steel influence both corrosion resistance and microstructure and their effects depend on the overall composition and processing conditions. Chromium enables the formation of the passive surface film and promotes ferrite formation, while nickel stabilises austenite and contributes to ductility and toughness. Molybdenum improves resistance to pitting and crevice corrosion in many chloride-containing environments, although its presence does not

make a grade immune to these forms of attack. Nitrogen, when retained in solid solution in suitable austenitic and duplex grades, increases strength, stabilises austenite and improves resistance to localised corrosion. Carbon also contributes to strength and is particularly important for the hardness obtained by quenching martensitic stainless steels. Its role therefore differs between stainless steel families, and increasing its content is not beneficial for every application.

In austenitic stainless steels, sufficient exposure to elevated temperatures during welding or subsequent service can cause chromium rich carbides to precipitate along grain boundaries. This precipitation removes chromium from the immediately adjacent regions, reducing their ability to maintain passivity and increasing susceptibility to intergranular corrosion. The resulting condition is known as sensitisation, and its development depends on carbon content, temperature and exposure time. The letter L in 316L identifies a low-carbon grade, with a maximum carbon content of 0.03% by mass and the main benefit in welded fabrication is reduced susceptibility to sensitisation and the associated intergranular corrosion.

Table 1. Properties that should not be confused

Property	Meaning	Hospital example
Yield or proof strength	Resistance to permanent deformation	A trolley frame should not remain bent after normal loading.
Tensile strength	Maximum engineering stress in a tensile test	It is different from the stress at final fracture.
Stiffness	Resistance to elastic deflection	Frame geometry matters as well as elastic modulus.
Hardness	Resistance to local indentation	A cutting edge needs a suitable hardened structure.
Toughness	Ability to absorb energy before fracture	Useful for parts exposed to impact.

2. Stainless steel families and grade selection

There are five stainless steel families that differ in structure and processing response as austenitic grades are common in hospital equipment and welded components and other types offer different combinations of hardness, strength, cost and corrosion resistance.

Table 2. Stainless steel grades

Grades	Main feature	Typical relevance
Austenitic	Good ductility and weldability; usually low magnetic response when annealed	Furniture, vessels and process tubing
Ferritic	Chromium alloy; usually low nickel percent; magnetic	Panels and selected kitchen components
Martensitic	Can be hardened by heat treatment; magnetic	Cutting instruments and wear-resistant parts
Duplex	Mixture of ferrite and austenite; high strength	Selected demanding water and plant services
Precipitation hardening	Strength obtained through controlled ageing	Specialised mechanical components

Table 3. Grades commonly used in healthcare facilities

Grade	Composition idea	Selection point
304	Often described as an 18Cr–8Ni austenitic steel	A useful starting point for general indoor equipment.
316	Cr–Ni steel with about 2–3% Mo	Often preferred over 304 when chloride exposure is more demanding.
316L	Low-carbon version of 316	Useful for welded equipment and tubing; the surface still needs protection.

430	Ferritic steel with about 16-18% Cr	Suitable for selected mild indoor environments; less versatile in wet service.

These are descriptive compositions, not purchasing limits as the exact limits depend on the product standard. The material order should identify the standard, grade, dimensions, delivery condition and any required certificate. A trade name such as surgical steel is not enough to define composition or performance.

Select for the actual environment

Stainless steel selection should begin with the conditions that the component will experience during normal operation, cleaning and periods of inactivity. Relevant factors include the composition and pH of the service fluid, chloride concentration, temperature, duration of wet contact and the possibility of stagnation or deposit formation. Cleaning and disinfection procedures also need consideration because chemical concentration, contact time and inadequate rinsing can create conditions more aggressive than normal service. These factors should be assessed together with mechanical loading, surface finish, joint design and the proposed welding method. Grade 430 may be adequate for an indoor wall panel that remains mainly dry and is exposed to mild cleaning conditions. For a welded wash area with frequent wetting, grades such as 304L or 316L are common candidates, but the choice depends on the actual chemical exposure. The molybdenum in 316L improves resistance to localized corrosion in chloride environments, although more demanding conditions may require a suitably selected duplex or higher-alloyed austenitic grade. Wet exposure alone is therefore insufficient to define the required material.

Magnetic attraction cannot reliably identify a stainless steel grade or establish its corrosion resistance. Ferritic and martensitic stainless steels are ferromagnetic, and duplex grades also respond strongly because their microstructure contains ferrite. Austenitic grades generally show little attraction in the solution-annealed condition, but cold deformation can transform part of the austenite into magnetic martensite. Austenitic weld metal may also respond to a magnet because it contains retained delta ferrite. A magnetic response is therefore an indication of the phases present rather than a direct measure of material quality or suitability for a particular environment. For equipment intended for use near an MRI scanner, a simple magnet test is insufficient because safety

also depends on the complete item, its geometry and its interaction with the magnetic and radiofrequency fields. Suitability for healthcare engineering usage must be established through the relevant assessment and documented conditions of use. Material identification should be supported by traceable markings and a material certificate, with chemical analysis where identification is uncertain. Conventional handheld X-ray fluorescence can measure elements such as chromium, nickel and molybdenum and help distinguish common alloy compositions, but it cannot measure the low carbon concentrations needed to verify the L designation in 316L. Where carbon verification is required, a suitable method such as spark optical emission spectroscopy, calibrated for low-carbon stainless steels, should be used.

3. Corrosion in the hospital environment

Corrosion develops through electrochemical interactions between a metal and its environment. In hospitals, stainless steel can lose its protective passivity through the combined effects of chlorides, persistent moisture, temperature, deposits and unsuitable cleaning practices. Most of a surface may remain apparently unaffected while localised attack progresses beneath deposits or within joints.

Local corrosion mechanisms

Pitting corrosion begins when the passive film breaks down locally, often in the presence of chloride-containing water or chemical residues. As the pit develops, the chemical conditions inside it become different from those in the surrounding liquid, allowing corrosion to progress beneath the surface even when the visible opening remains small.

Crevice corrosion occurs in confined areas, such as beneath gaskets, washers or deposits, where limited exchange with the surrounding liquid changes the local oxygen concentration and chemical conditions. Although a more resistant alloy can reduce the risk, removing the crevice or improving drainage may provide a more effective solution than changing the steel grade alone.

Galvanic corrosion can occur when different metallic materials are electrically connected in the presence of a conductive liquid, causing the less noble material to corrode more rapidly. The relative size of the exposed surfaces also affects the severity of the attack, particularly when a small anodic component is connected to a much larger cathodic surface. Contact between dry metals does not, by itself, produce this form of corrosion.

Sensitization develops when thermal exposure promotes chromium carbide precipitation and leaves the regions near grain boundaries depleted in chromium, reducing their corrosion resistance. Low-

carbon grades are less susceptible to this process, although they can still suffer from other forms of corrosion. Chloride stress corrosion cracking involves a different combination of conditions, in which a susceptible material is exposed to tensile stress and a chloride-containing environment, often at elevated temperature. Surface discoloration alone is insufficient to identify either mechanism. The stainless teel surfaces must be inspected for damage marks as presented in table 4.

Table 4. What an observed defect may mean

Observation	Possible explanation	What to check
Brown marks after maintenance	Embedded iron, residues or corrosion	Tools used, cleaning response and surface damage
Pits near a sink drain	Deposits, chloride concentration or a crevice	Water retention, grade and cleaning history
Blue or dark weld root	Oxidation during welding	Purge record, internal condition and acceptance criteria
Repeated staining across a batch	Common processing or water problem	Washer, rinse water and shared treatment route

These observations help guide the investigation, but they are not sufficient on their own to determine the cause. Iron contamination can produce rust staining, while weld heat tint can indicate oxidation associated with reduced local corrosion resistance.

The condition should be documented before cleaning or repair, with photographs of the affected area, identification of the component and a record of whether the marks follow a weld, gasket or water line. After cleaning with an approved method, the exposed surface should be inspected for pits or other material loss, since removing a stain does not confirm that the underlying metal is undamaged. For medical devices, withdrawal from service and further assessment should follow the manufacturer's instructions and the applicable local procedure.

The significance of a defect depends on its location and function. Superficial staining on a dry plant-room support may require routine maintenance, whereas pitting on a reusable instrument can

impair cleanability and serviceability. Decisions should consider damage depth and extent, mechanical integrity and hygiene requirements, rather than appearance alone.

4. Surface condition and cleaning

Cleanability and antimicrobial properties

Ordinary stainless steel provides a durable surface that can withstand repeated cleaning, but its chromium and nickel content does not give it reliable antimicrobial properties. Dirt and microorganisms can remain in scratches, joints or surface deposits, particularly where access for cleaning is limited. Cleaning removes dirt and other contamination, while disinfection and sterilization serve different purposes and must follow procedures validated for the intended application. A smooth finish generally makes dirt easier to remove, although average roughness alone cannot describe how easily a surface can be cleaned. Two surfaces with the same Ra value may contain different grooves, pits or embedded particles that affect their behaviour during cleaning. Since Ra represents the arithmetic mean of the absolute profile deviations from the mean line, it does not fully describe individual defects or the shape of surface features. A mirror finish should therefore not be taken as proof that a component meets the required hygiene conditions.

Finishing processes

Mechanical polishing modifies the surface through abrasion, using dedicated tools and suitable abrasives to limit the risk of contamination with iron particles. The direction and depth of the resulting marks deserve attention, especially in areas where liquids or deposits may collect, while excessive grinding can reduce the component thickness or change the geometry of a joint. Pickling removes oxide scale and the affected surface layer, whereas passivation treatments remove certain contaminants and help establish a passive surface. Passivation does not repair existing pits and cannot replace the removal of heavy oxide formed during welding. Electropolishing removes a thin layer of metal electrochemically and can smooth small surface irregularities, provided that the treatment conditions are appropriate for the material and component. Chemical treatments require controlled processing, adequate rinsing and inspection of the finished surface.

Surface finish requirements should reflect the function of the component, since a pharmaceutical process tube, an instrument joint and a trolley shelf are exposed to different conditions and cleaning

procedures. Rather than applying one roughness limit to all hospital equipment, the specification should define the measurement method and location, together with the surface defects that are unacceptable for the intended use.

Coordinate cleaning with material durability

The cleaning product, concentration and contact time must be compatible with the equipment instructions. More concentrated is not automatically more effective in practice. Excessive exposure may damage surfaces, seals and adhesives. Required wet contact time must still be achieved. Do not shorten an approved disinfection process to protect the metal without an authorised review.

Rinsing and drying are carried out where the product label and equipment instructions require them. Pay attention to joints, hinges and horizontal ledges. Carbon steel wool and contaminated brushes can introduce particles that later rust. Abrasive treatment should never be used as an improvised repair of a medical device.

Tyan et al. tested two bleach wipes on stainless steel and observed corrosion in their test conditions [2]. This supports checking chemical compatibility, but does not establish a service-life prediction for every hospital surface or justify changing a validated cleaning product without assessment.

A practical cleaning review

When damage appears after a product change, compare the old and new procedures. Record the active agent, dilution, contact time, application frequency, rinsing instructions and drying conditions. Check what staff actually do. Then compare affected and unaffected equipment of known grade. The cause may be a process deviation, a material difference or both.

5 Applications in healthcare facilities

Furniture and fixed surfaces

Worktops, sinks, cabinets, trolleys and handrails need adequate strength and surfaces that remain accessible for cleaning. Welded corners should not retain liquid. Open tube ends, exposed threads and overlapping sheet joints can create dirt traps. Handles, wheels and seals deserve the same attention as the main stainless steel frame.

For a trolley, the design must consider repeated loading, impact and cleaning. A stronger alloy does not compensate for a weak joint or an unstable wheel arrangement. For a sink, drainage, splash control and access around the outlet can matter as much as the nominal grade. Specify the complete component, not only the sheet material.

Reusable instruments

Scissors and other cutting instruments often use hardened martensitic steels because edge retention is essential. Austenitic steels can suit non-cutting parts where toughness and corrosion resistance are more important. Hinges, serrations and narrow channels are difficult areas because they can retain residues and moisture.

The reprocessing route belongs to the device. Staff must follow the manufacturer's validated instructions for cleaning, disinfection or sterilization, inspection and reuse. An instrument that is stainless is not automatically suitable for every chemical or thermal cycle. Defects that affect function or cleanability require assessment through the established service procedure.

Implants and components in contact with the body

General-purpose 316L is not interchangeable with certified implant material. ISO 5832-1 addresses wrought stainless steel for surgical implants and identifies the corresponding alloy as UNS S31673. Material purity, processing, mechanical properties, traceability and biological evaluation all matter. Hospital fabrication stock should never be treated as a substitute.

Diagnostic equipment and imaging areas

Probe housings, supports and protective covers may combine stainless steel with polymers, ceramics, electronics and adhesives. The least resistant part may determine the permitted cleaning route. Heating a metal enclosure can damage an internal sensor even when the enclosure itself remains unchanged.

MRI suitability must be established for the complete item through its documented safety status and conditions of use. A grade label or a simple magnet test is insufficient. Geometry, magnetic response, conductive paths and device function can all affect suitability.

Plant and service areas

Tanks, sterilizer interfaces, drain pans and selected ventilation components can benefit from stainless construction. Selection remains specific to the operating conditions. Austenitic stainless steel has relatively low thermal conductivity compared with copper, so its use in heat exchangers reflects corrosion resistance and design choices, not exceptional conductivity.

6. Water and utility pipework

A hospital contains several types of water and utility service. Potable water, treated water, heating circuits, steam and wastewater differ in chemistry, temperature and hygiene requirements. A material that works well in one line may fail in another. Begin the design with a written service description.

Information needed before selection

Record normal and maximum temperature, pressure, water chemistry, disinfectant exposure, operating pattern and expected shutdowns. Include cleaning and commissioning conditions. A short chemical treatment may be more severe than normal service. Where chemistry is uncertain, a water analysis is more useful than an unsupported assumption that 304 or 316L will be sufficient.

Stagnation and deposits affect both water quality and corrosion. Avoid unnecessary dead ends and consider how infrequently used branches will be managed. Tanks and equipment connections need suitable drainability and access. Good alloy selection cannot correct a system that retains contaminated liquid in inaccessible pockets.

Thermal expansion

Austenitic stainless steel expands when heated. Supports should carry the weight while allowing the intended movement. Excessive restraint can transfer loads to welds, valves and equipment nozzles. Anchors, guides and expansion provisions must be designed as a system.

Table 5. Stainless steel and copper

Criteria	Stainless steel	Copper
Fabrication	Welding is common in hygienic tube systems.	Brazing is established in medical gas installations.

Mechanical response	Higher elastic modulus; geometry still controls stiffness.	Lower elastic modulus and generally easier forming.
Heat transfer	Lower conductivity; corrosion resistance may justify use.	High conductivity is useful in heat transfer.
Selection constraint	Grade, surface condition and weld quality.	Service compatibility, tube cleanliness and joint quality.

Avoid treating copper's antimicrobial surface behaviour as proof that a copper pipeline delivers sterile fluid. Water chemistry, temperature, flow and maintenance remain relevant. Similarly, stainless steel does not prevent biofilm formation simply because its surface is passive.

A recent study of a simulated plumbing system containing 304 stainless steel found different metal release under free chlorine and monochloramine exposure [3]. The result reinforces the need to evaluate disinfectant chemistry. A hospital cannot select a water disinfectant on corrosion performance alone; microbiological control and the whole water system must be assessed.

7 Medical gas systems and standards

Medical gas pipelines connect supply equipment to clinical areas. Their performance depends on gas identity, continuity of supply, cleanliness, pressure control and correct connections. A sound pipe joint is only one requirement. A leak-tight line carrying the wrong gas is still unsafe.

Different standards serve different purposes

Table 6. Standards example

Reference	Main scope	What it does not establish alone
ISO 7396-1	Systems for compressed medical gases and vacuum.	The suitability of any unverified tube or assembled device.
ISO 7396-2	Anaesthetic gas scavenging disposal systems.	A substitute for medical gas supply requirements.

EN 13348	Seamless round copper tubes for medical gases or vacuum.	Compliance of the complete installed system.
ISO 8573-1	Compressed air contaminant and purity classes.	Full medical air quality or medical pipeline compliance.

The scope distinction is important. Anaesthetic gas scavenging is addressed separately in ISO 7396-2. ISO 8573-1 classifies particles, water and oil in compressed air and also identifies other contaminants. Industrial air classification alone does not demonstrate that air is suitable for administration to a patient.

Material selection and cleanliness

Copper tube meeting the applicable medical gas requirements is established in many installations. Stainless steel may be considered where the governing requirements and approved system design allow it. A statement that 316 is corrosion resistant is not sufficient evidence of oxygen-service suitability or system compliance.

Tube, fittings, valves and joining consumables must have the required identification and cleanliness. Protect clean internal surfaces during storage, cutting and assembly. Oil, grease, particles and internal oxide are unacceptable where they conflict with the service requirements. Oxygen compatibility needs specific attention because oxygen-rich conditions can greatly increase combustion hazards.

Joining and welding

Brazing joins components by melting a filler metal while the base materials remain solid, whereas fusion welding processes, such as TIG and laser welding, also melt the base metal in the joint area. In both cases, the approved joining procedure defines the preparation, protective gas, consumables and inspection requirements. Internal gas protection helps limit oxide formation during joining, with the gas type and flow selected according to the applicable procedure.

Before the system is released for clinical use, commissioning must confirm that it operates correctly through checks for leakage, cross-connections, identification, supply performance, alarms and gas quality, as applicable. The responsible specialists establish the test sequence and acceptance

criteria, since a pressure test alone cannot demonstrate that the system meets all requirements for clinical service.

When an existing installation is extended or repaired, the work must be planned around the affected clinical areas and an authorised isolation procedure, including temporary supply arrangements where needed. Communication with clinical staff and approval before returning the system to service are part of this process, while updated drawings and intervention records provide the information needed for future maintenance.

The standards applied must correspond to the edition and national adoption required for the project, taking account of any relevant amendments or replacements.

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