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Titanium in healthcare engineering

Class content material

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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.

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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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1 Titanium in healthcare engineering

1.1 What titanium is

Titanium is a metallic element with the chemical symbol Ti and atomic number 22, known in engineering for its low density, useful mechanical strength and resistance to many corrosive environments. It occurs naturally in minerals such as ilmenite and rutile, rather than as a ready to use metal, and its production requires several stages of extraction, refining and melting before sheet, bar, tube or powder can be supplied [1].

The metal should not be confused with titanium dioxide pigment, which is a chemical compound widely used in paints and other products. A coating that contains titanium dioxide does not give a steel component the same properties as a component made from titanium, and the word titanium on a product description is not enough to identify its composition.

1.2 Why it matters in healthcare

Titanium has two main roles in healthcare engineering: it can form part of an implant or medical device, and it can be used in selected equipment that supports the hospital infrastructure. These applications require different specifications, because a heat exchanger plate is assessed mainly for its operating environment, while an implant also needs evidence about its interaction with tissue and its long term mechanical behaviour.

Figure 1. A high-purity titanium crystal bar produced by the iodide process [2]

2. Structure properties and corrosion behaviour

2.1 Density and mechanical response

Commercially pure titanium has a density of about 4.51 g/cm³, while Ti-6Al-4V is about 4.43 g/cm³, compared with approximately 7.9–8.0 g/cm³ for common austenitic stainless steels. A titanium component of the same volume can therefore weigh about 43–45% less, although the final saving depends on whether the design needs a different thickness or shape [3-5].

Strength and stiffness describe different behaviour. Titanium alloys can carry high loads before permanent deformation, but their elastic modulus is generally lower than that of steel, which means that a component of the same geometry may deflect more under the same load. Representative room-temperature moduli are about 105 GPa for Grade 2, 114 GPa for Grade 5 and 200 GPa for 304 stainless steel; these are comparison values rather than guaranteed design data [3-5].

2.2 The role of the crystal structure

At room temperature, unalloyed titanium normally has an alpha structure with a hexagonal crystal arrangement, while the beta structure has a body-centred cubic arrangement and is stable at higher temperature. Alloying elements and heat treatment influence which phases remain in the finished material, allowing manufacturers to obtain different combinations of strength, ductility and stiffness.

The terms alpha, alpha plus beta and beta alloy therefore describe metallurgical families rather than quality levels. Processing history also matters, because two parts with a similar chemical composition can have different grain structures, residual stresses and fatigue performance after forging, welding or additive manufacturing [6].

2.3 Protection from the passive film

Titanium reacts readily with oxygen, but in air and many aqueous environments this reaction produces a thin protective oxide film that limits further attack. This explains why a reactive metal can perform well in service, although resistance depends on the stability of the film under the actual temperature, chemistry and mechanical conditions.

Titanium is often effective in chloride-containing water, but it is not resistant to every chemical. Reducing acids, fluoride-containing acidic solutions and some hot crevice conditions require particular assessment, while contact with another metal in a conductive liquid can create a galvanic couple that accelerates corrosion of the less noble material [6].

Inside the body, wear, fretting and inflammatory chemistry can disturb the surface and release ions or particles, even when the bulk material remains intact. The review by Prestat and Thierry [7] describes how aggressive species formed during inflammation can interact

with mechanical damage, so the word biocompatible should not be interpreted as a promise that degradation or an adverse reaction is impossible.

3. Commercially pure titanium grades

3.1 What the grade number means

Grades 1, 2, 3 and 4 are commonly described as commercially pure titanium, although they contain controlled amounts of oxygen, iron and other elements. Differences in these limits influence strength and ductility, with the lower-numbered grades generally easier to form and the higher-numbered grades providing greater strength. A grade number should always be read together with the product specification and supplied condition.

Commercially pure does not mean laboratory-pure or free from every trace element, and an industrial sheet cannot be accepted for an implant simply because its supplier calls it Grade 2. ASTM F67 covers four grades of unalloyed titanium for surgical implant applications, including requirements for composition and mechanical properties, but conformity of the raw material is only one part of demonstrating the suitability of a finished device [8].

3.2 Grades 1 and 2

Grade 1 is useful when extensive forming and high ductility are important, for example where thin sheet must take a complex shape without cracking. Its lower strength may require a thicker section than another grade, so it should not be selected only because it is easier to bend.

Grade 2 provides a practical balance of strength, formability, weldability and corrosion resistance, and is widely considered for industrial equipment exposed to suitable corrosive liquids. Heat exchanger plates, tubes and selected process components are relevant examples, while medical applications require the corresponding medical material specification. The Metalcor Grade 2 datasheet gives a minimum tensile strength of 345 MPa and a minimum yield strength of 275 MPa for its stated material conditions [2].

3.3 Grades 3 and 4

Grades 3 and 4 offer higher strength within the commercially pure family, with some reduction in forming capability compared with Grades 1 and 2. Grade 4 is used in dental implant applications where the material must combine corrosion resistance with adequate strength, although the device design and manufacturing route remain central to its performance.

A stronger grade does not automatically provide better performance in every hospital application, because an increase in strength may bring little benefit to a lightly loaded panel

or a component limited by stiffness. Conversely, a small threaded part may need strength that cannot be obtained from the softer grades without changing its dimensions.

3.4 Information required when ordering

An order should identify the grade, product standard, dimensions, delivery condition, surface requirements and certification, with traceability maintained from the received batch to the finished part. The certificate should be checked against the purchase specification rather than filed without review, especially when material is bought through several distributors.

For implants, the manufacturer must also control processing, cleaning and final verification, because later operations can introduce contamination or defects that were not present in the original stock. The supplied material and the finished device should therefore be treated as related but separate stages of acceptance.

4. Titanium alloys and medical specifications

4.1 Grade 5 and Grade 23

Grade 5 is the familiar Ti-6Al-4V alloy, containing approximately 6% aluminium and 4% vanadium by mass, with titanium as the balance. It belongs to the alpha plus beta family and offers substantially higher strength than commercially pure Grade 2, making it useful where a compact section must carry a significant load. A supplier datasheet lists a minimum tensile strength of 895 MPa for its stated condition, but the value required for a particular product must come from the applicable specification.

Grade 23 is the extra-low-interstitial form of Ti-6Al-4V, usually written Ti-6Al-4V ELI, with tighter limits on certain interstitial elements to support properties such as ductility and fracture toughness. It is frequently associated with implant manufacture, although a commercial Grade 23 designation alone does not establish compliance with a medical specification.

ASTM F136 addresses wrought annealed Ti-6Al-4V ELI for surgical implant applications and covers chemical, mechanical and metallurgical requirements. A component supplied for implantation must satisfy the specified material and device requirements, so replacing an approved ELI product with a general Grade 5 product is not a routine substitution .

4.2 Grades used in tubing and corrosive service

Grade 9, Ti-3Al-2.5V, provides an intermediate combination of strength and formability and is used in applications such as thin-walled tubing. Its suitability for a healthcare product depends on the product specification and design, rather than on the fact that tubing of this alloy is available.

Grade 7 contains a small palladium addition that improves resistance in certain environments where commercially pure titanium may be less satisfactory. Grade 12 contains nickel and molybdenum additions and is another industrial option for selected corrosive conditions. These grades are relevant to equipment selection, but they should not be treated as interchangeable with the grades normally specified for implants.

4.3 Other biomedical alloy families

Ti-6Al-7Nb was developed as an alternative biomedical alloy containing niobium instead of vanadium, while beta alloys containing elements such as niobium, molybdenum, tantalum or zirconium are studied and used in selected applications to obtain a lower elastic modulus. Some compositions have established material specifications, while others remain at the research stage [8].

Nickel-titanium, commonly called nitinol, is a separate alloy family valued for shape memory and superelasticity, rather than simply another version of commercially pure titanium. Its nickel content and processing requirements mean that statements about the composition or biological behaviour of commercially pure titanium cannot be transferred directly to nitinol.

The grade list should therefore be used as a starting point for selection. The engineer still needs to establish the loading, environment, product form and regulatory route before deciding which material is appropriate.

5. Titanium in hospital infrastructure

5.1 Heat exchangers and demanding water circuits

Titanium is most relevant to hospital infrastructure when a particular liquid creates a corrosion problem that cannot be managed economically with the usual material. A coastal cooling system using seawater, a saline rehabilitation pool or a specialised water treatment process may justify titanium heat transfer surfaces, provided that the complete equipment is designed for the fluid, temperature and pressure.

Manufacturers offer plate heat exchangers with titanium plates for saltwater applications, including the Alfa Laval [9]. This establishes an available engineering option, rather than evidence that every hospital should install titanium equipment. The selection should consider both circuits, the cleaning chemicals and the consequences of leakage.

5.2 Design the complete assembly

The plates or tubes may be titanium while the frame, bolts, connections and gaskets are made from other materials, so the corrosion resistance of one part does not describe the

reliability of the whole assembly. Gasket ageing, fouling, poor flow distribution or an unsuitable connection can still cause failure even when the titanium remains sound.

Titanium does not automatically give a higher heat transfer rate than stainless steel, because thermal performance depends on alloy conductivity, wall thickness, surface condition and flow on both sides. The engineer should compare the manufacturer's calculated duty and pressure loss, then include inspection access and replacement parts in the purchase decision.

6. Hospital equipment fabrication and maintenance

6.1 Instruments and equipment components

Titanium is used in selected surgical instruments, implantable device housings and lightweight mobility equipment, where corrosion resistance and reduced mass can be valuable. A lighter instrument may reduce handling effort during a long procedure, while a titanium wheelchair frame can reduce the mass moved by the user, although the benefit depends on the complete design.

Titanium is not the default material for every cutting edge, sliding contact or hospital fitting. Its tendency to gall and its relatively poor resistance to some wear conditions require attention to contact pairs, surface treatment and lubrication where permitted. A hardened stainless steel may remain more suitable for an instrument that needs a durable cutting edge, while titanium may be useful for its handle or another component.

6.2 Manufacturing needs suitable control

Machining titanium requires attention to heat at the cutting zone, tool condition and chip removal, because low thermal conductivity and chemical interaction with the tool can affect surface integrity and tool life. Machining conditions should come from a qualified process for the alloy and component, while fine chips and powder require suitable fire and dust controls.

TIG and laser welding can be used for titanium when cleanliness and shielding are adequate, but the hot weld, heat-affected zone and root need protection from atmospheric contamination. Oxygen, nitrogen and hydrogen pickup can reduce ductility, so shielding must continue over the relevant hot surfaces as the joint cools. TWI describes the use of trailing shields and backing protection for this purpose [10].

Surface colour can provide useful evidence about oxidation, but a bright appearance alone cannot establish weld integrity or the absence of contamination. Acceptance should follow the qualified procedure and required inspection, with particular care when a repair could change the dimensions or mechanical properties of a medical device.

6.3 Cleaning and service records

A titanium surface can be cleaned and reprocessed when the product has been designed and validated for the relevant method, but the metal itself is not reliably antimicrobial. The cleaning agent, concentration, temperature and contact time must be compatible with the full assembly, including seals, coatings and joined materials.

Use the device manufacturer's instructions for reusable instruments and the equipment supplier's procedures for facility components, rather than selecting a treatment only because it worked on stainless steel. An unauthorised polishing or chemical treatment can alter a critical surface, remove identification or affect a coating that forms part of the device specification.

Maintenance records should identify the actual grade and component, together with the operating conditions, observed damage and repair history. Where corrosion recurs, investigate the environment and design instead of replacing the damaged part with the same material without understanding why it failed.

7. Titanium in orthopedic implants

7.1 Supporting and replacing bone

Titanium and its alloys are used in fracture fixation plates, screws, spinal components and selected parts of joint replacements, where strength, corrosion resistance and tissue compatibility must be combined. The material is particularly useful for components intended to transfer load to bone, but the design must also withstand repeated loading during normal movement.

A hip replacement may contain a titanium stem or acetabular shell together with ceramic, polymer or cobalt alloy components, so the whole prosthesis should not be described as titanium simply because one major part is made from it. Bearing surfaces have different wear requirements from the parts intended to attach to bone.

7.2 Bone attachment and load sharing

Osseointegration describes a direct structural and functional connection between living bone and an implant surface, and suitable titanium surfaces can support this process when the clinical and mechanical conditions are favourable. It does not occur simply because titanium is present; initial stability, surface condition, surgical technique and patient factors also influence the result.

Titanium's lower modulus compared with stainless steel can reduce stiffness mismatch, but solid titanium is still much stiffer than bone in many relevant loading directions. An overly stiff implant may carry a large share of the load and reduce the stimulus experienced by the

surrounding bone, a problem known as stress shielding. Alloy selection, geometry and porosity must therefore be considered together [12]. Figure 2 show the most used titanium hip implants

Figure 2. Titanium hip implants [11]

8. Dental implants and other biomedical applications

8.1 Dental and craniofacial components

Titanium is used for dental implant bodies and selected abutments, where the connection with bone, soft tissue response and mechanical loading all need consideration. Commercially pure grades and titanium alloys are selected according to the device design, while surface treatment is used to control the interface with surrounding tissue rather than merely improve appearance.

Figure. Titanium dental implants [12]

8.2 Housings and imaging considerations

Titanium is also used for selected implantable electronic device housings, where the enclosure must protect internal components while remaining suitable for long-term contact

with tissue. The assembled device includes seals, electrical feedthroughs and other materials, so its reliability cannot be inferred from the housing material alone.

Titanium is weakly magnetic, but a titanium-containing implant or instrument should not automatically be described as safe for MRI. Heating, forces, image artefacts and the behaviour of other components must be assessed for the complete device, and the applicable MR safety label and scanning conditions must be checked before use.

9. Bioengineering and current development

9.1 Porous structures and additive manufacturing

Additive manufacturing can produce titanium components with internal channels, lattice structures and patient-specific shapes that would be difficult to obtain by conventional machining. In biomedical engineering, this allows designers to explore surfaces for bone attachment and structures with lower effective stiffness, while retaining solid material where loads must be transferred.

Porosity changes more than the mass of the component. Pore geometry, connection between pores and the thickness of the load-bearing struts influence stiffness, fluid access and fatigue resistance, so a highly porous design is not automatically a better implant. The structure must be assessed under realistic loading and manufactured consistently enough for the analysis to remain meaningful.

The U.S. Food and Drug Administration guidance on additive manufactured medical devices describes considerations for design, manufacturing, material control and final testing, including issues that arise from the build process and subsequent operations. Build orientation, retained powder, surface condition and post-processing need to be addressed as part of device development, rather than treated as minor finishing details.

9.2 Surface engineering

Surface roughening, anodising, porous layers and calcium phosphate coatings can be used to alter the interaction between titanium and tissue, while other treatments aim to improve wear or limit bacterial attachment. The chosen surface must remain stable through manufacture, cleaning, sterilisation and service, and any change requires assessment of both its intended benefit and possible unwanted effects.

Recent research also investigates surfaces that combine bone attachment with antibacterial activity, but a favourable laboratory result does not establish a reduction in clinical infection. Bacterial tests, cell response, coating durability and evidence from suitable biological models answer different questions, and none should be used as a substitute for the others [13].

9.3 Lower modulus alloys and evidence of performance

Beta titanium alloys offer routes to lower elastic modulus than conventional Ti-6Al-4V, while their strength and fatigue behaviour depend on composition and processing. Research therefore seeks combinations that carry the required loads without transferring too much load away from bone, rather than reducing stiffness at any cost.

For the healthcare engineer, the useful distinction is between an established product and a promising material concept. A new alloy, coating or printed lattice should be assessed through its intended use, manufacturing consistency and available evidence, with clinical claims kept separate from what has only been measured in a laboratory.

When reviewing a proposed innovation, ask which failure mode it addresses and which new risks it introduces, then compare it with the existing solution under the same conditions. A successful design should improve a relevant outcome, such as fixation, durability or handling, rather than only produce a more complex shape.

10. Titanium compared with stainless steel

10.1 Compare the grades and the component

A meaningful comparison must identify the titanium grade and the stainless steel grade, because neither material name describes a single set of properties. Grade 2 titanium should not be assigned the strength of Ti-6Al-4V, while ordinary 304 or 316L stock should not be treated as equivalent to stainless steel supplied to an implant specification.

Titanium offers lower density and, for several alloys, high strength relative to mass, which can benefit implants, instruments and equipment that must be carried or moved. Stainless steel provides greater elastic stiffness for the same shape and is widely available in many product forms, which can make it more practical for frames, work surfaces, cabinets and general hospital fittings.

10.2 Weight saving does not guarantee equal stiffness

Consider a solid component with a volume of 100 cm^3. Using the representative densities cited earlier, Grade 2 titanium would weigh about 451 g and 304 stainless steel about 790 g, giving a calculated mass reduction of approximately 43%. This comparison applies to equal volume and does not establish that the two components will carry the same load or deflect by the same amount.

For a simple axial member, stiffness is proportional to elastic modulus multiplied by cross-sectional area and divided by length. If the length is fixed, replacing 200 GPa stainless steel with 105 GPa titanium would require about 1.90 times the area to keep the same axial

stiffness. The resulting mass ratio is about 1.90 × 4.51 / 7.9 = 1.09, so the equal-stiffness titanium member would be slightly heavier in this simplified example. Bending designs can respond differently because section geometry has a strong influence.

10.3 Corrosion wear and hygiene

Titanium can offer a clear advantage in suitable chloride environments, while stainless steel remains effective in many hospital applications when the grade, finish and cleaning practice are appropriate. Neither choice removes the need to avoid deposits, retained liquids, damaged joints or incompatible chemicals, and a switch to titanium should follow an assessment of the actual failure mechanism.

For sliding or cutting contacts, untreated titanium may be less suitable than a hardened stainless steel, and surface engineering may be needed to obtain acceptable wear behaviour. Both materials can support biofilms and require cleaning; corrosion resistance should not be confused with antibacterial activity.

10.4 A practical selection decision

For a dry cabinet or trolley shelf, stainless steel will often provide adequate performance with simpler purchasing and repair arrangements, while titanium may be justified for a saline heat exchanger or a biomedical component where its specific properties address a defined need. In each case, compare the complete design, fabrication route and expected service conditions.

The choice should record the reason for selecting the material, the evidence used and the conditions that could change the decision. This makes future maintenance and replacement more reliable than relying on a general statement that titanium is always better or stainless steel is always cheaper.

11 Purchase price and cost over service life

11.1 A price comparison

Retail prices checked on June 2026 provide a practical example of the difference between raw materials, although they are not a quotation for hospital procurement. Usually shops lists a Grade 2 titanium sheet measuring 1000 × 500 × 1 mm at EUR 180.20 including VAT and excluding delivery, while a 304 stainless steel sheet of the same nominal dimensions is at EUR 44.5.

11.2 Why the finished part costs more

Titanium extraction and processing, smaller production volumes and specialised fabrication contribute to its cost, while machining time, tooling, shielding gas, inspection and material losses affect the price of a finished part. Medical products add design verification,

traceability, cleaning, packaging and regulatory work, which may be more important than the mass of metal used.

A small implant made from titanium cannot therefore be priced by multiplying its weight by a sheet price, and a hospital heat exchanger should be compared as a complete unit with the required duty, connections and certification. Grade 5, Grade 23, powder and medical bar stock need their own quotations, because a fixed multiplier from Grade 2 sheet would be unreliable.

11.3 Include maintenance and downtime

A simple example can show how a higher purchase price might be recovered. If a titanium assembly costs EUR 3000 more than a stainless steel alternative and avoids EUR 600 per year in maintenance and downtime, the simple payback is five years. These figures are assumptions for the calculation, not measured savings from a hospital installation.

A purchasing decision should compare costs over the same service period and include replacement, cleaning, repair access and interruption of the clinical service, with future costs discounted where appropriate. If the stainless steel component already performs reliably, the additional cost of titanium may bring little financial benefit; where repeated corrosion causes shutdowns, the same premium may be easier to justify.

12 References

[1] Smith, D. B., Solano, F., Woodruff, L. G., Cannon, W. F., & Ellefsen, K. J. (2017). Titanium. In Geochemical and mineralogical maps, with interpretation, for soils of the conterminous United States (Scientific Investigations Report 2017-5118). U.S. Geological Survey. https://pubs.usgs.gov/sir/2017/5118/elements/Titanium/Ti_txt.html

[2] https://en.wikipedia.org/wiki/File:Titan-crystal_bar.JPG

[3] Metalcor. https://www.metalcor.de/en/datenblatt/122/

[4] Metalcor.. https://www.metalcor.de/en/datenblatt/125/

[6] Abd-Elaziem, W., Darwish, M. A., Hamada, A., & Daoush, W. M. (2024). Titanium-based alloys and composites for orthopedic implants applications: A comprehensive review. Materials & Design, 241, Article 112850. https://doi.org/10.1016/j.matdes.2024.112850

[7] Prestat, M., & Thierry, D. (2021). Corrosion of titanium under simulated inflammation conditions: Clinical context and in vitro investigations. Acta Biomaterialia, 136, 72–87. https://doi.org/10.1016/j.actbio.2021.10.002

[8] Niinomi, M., & Nakai, M. (2011). Titanium-based biomaterials for preventing stress shielding between implant devices and bone. International Journal of Biomaterials, 2011, Article 836587. https://doi.org/10.1155/2011/836587

[9] Alfa Laval. (n.d.). AQ2-MFM, 39 plates, titanium [Product listing]. https://shop.alfalaval.com/ro-ro/incalzirea-piscinei--c005/aq2-mfm-39-plates-titanium--1319832-

[10] TWI. (n.d.). Welding of titanium and its alloys: Part 1. https://www.twi-global.com/technical-knowledge/job-knowledge/welding-of-titanium-and-its-alloys-part-1-109

[11]https://www.lyfboat.com/knowledge-center/hip-replacement-implants-quick-comparison-guide/

[12] https://msdi-dental.com/2022/02/17/titanium-grades-in-dental-implants/

[13] Murugan, J., Durairajan, R., Sivakumar, S., Kartik, R., Manickam, A., Srinivasan, G., & Mohan, S. (2025). A critical review on multifunctional surface strategies for titanium alloys in bioactive and durable implants. Next Bioengineering, 1, Article 100009. https://doi.org/10.1016/j.nxbio.2025.100009

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