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Light metals and their alloys — Titanium and titanium alloys — Vocabulary

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 79, *Light metals and their alloys*, Subcommittee SC 11, *Titanium*.

This second edition cancels and replaces the first edition (ISO 28401:2010), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the title was changed from “Classification and terminology” to “Vocabulary”;

— new terms were added;

— some sentences were revised for clarity;

— the notations alpha and beta were changed from English to Greek;

— some abbreviated terms were removed;

— Annex A was revised and tables were added as additional normative text;

— Annex B was removed.

A list of all parts in the ISO 28401 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

There are many technical terms related to titanium used in national standards.

Unifying and interpreting these technical terms worldwide, so that specifications can be understood accurately around the world, is essential for international trade in common titanium products.

There is a need to classify technical terms related to titanium and establish a common interpretation of each term.

Light metals and their alloys — Titanium and titanium alloys — Vocabulary

1 Scope

This document defines terms and definitions related to titanium and titanium alloys.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Material

3.1.1
titanium sponge
products of metallic titanium in a porous and sponge-like form, which are applied as titanium metal melting stock

Note 1 to entry: To produce titanium sponge, oxidized titanium ore is chlorinated to tetrachloride and is condensed and purified. Then the product is reduced with magnesium or sodium under an inert atmosphere.

3.1.2
alloy
metallic substance consisting of a mixture of the basic metallic element and other elements, such as alloying elements and impurities

Note 1 to entry: In this document, the most predominant element by mass fraction is titanium.

3.1.3
alloying element
metallic or non-metallic elements intentionally added to, or retained by, base metal to give special properties

3.1.4
impurity
metallic or non-metallic elements which are present but not intentionally added to, or retained by, a metal

3.1.5
wrought alloy
alloy primarily intended for the production of wrought products by hot and/or cold plastic forming

3.1.6
casting alloy
alloy primarily intended for the production of castings

3.1.7
master alloy
alloy intended for alloying elements added to molten or compacted titanium by controlling physical properties such as melting point, densities and dissolvability

3.1.8
heat-treatable alloy
alloy capable of being strengthened by a suitable thermal treatment

3.1.9
non-heat-treatable alloy
alloy capable of being strengthened only by cold working rather than by thermal treatment

3.2 Classification of phases and related terms

3.2.1
α phase
solid solution at low temperature with a hexagonal closed packed crystal structure

3.2.2
α phase stabilisers
alloy elements such as aluminium, oxygen, nitrogen and carbon that expand the α phase, which is the low temperature phase of titanium alloy, to high temperature and enhance the stability of the α structure

3.2.3
β phase
solid solution at high temperature with a body centred cubic crystal structure

3.2.4
β phase stabilisers
alloy elements such as iron, manganese, molybdenum and vanadium that expand the β phase, which is the high temperature phase of titanium alloy, to low temperature and enhance the stability of the β structure

3.2.5
α plus β phase
mixture of the α and β phases

3.2.6
β-transus temperature
temperature above which the crystal structure turns to the β phase

3.3 Classification of microstructure by morphology and related terms

3.3.1
microstructure by morphology
microstructure observed by an optical and/or a scanning microscope characterized by composition, processing and heat treating

Note 1 to entry: See Reference [2] for detailed classifications of titanium and titanium alloy microstructures, including microstructure photographs.

3.3.2
equiaxed α structure
polygonal or globular α structure with approximately equal dimensions in all directions

Note 1 to entry: In some types of α-β titanium alloys, most α structures are observed in a globular rather than equiaxed form. Therefore, this structure is sometimes called the globular α structure.

3.3.3
acicular α structure
microstructure in which β transforms the selected crystal planes by nucleation and growth or martensitically

Note 1 to entry: This microstructure is also called the Widmansttäten α structure.

Note 2 to entry: Depending on the aspect ratio and the existence state in the colonies, other names for this microstructure are platelet α structure, blocky α structure, basketweave α structure and lamellar α structure.

3.3.4
grain boundary α structure
α structure formed at prior β grain boundaries during cooling from the single β phase region

3.3.5
elongated α structure
grain microstructure in which the length of one of the three axial directions of the crystal grains is remarkably elongated

Note 1 to entry: The structure shows that the influence of plastic working remains strong or that it has failed to become equiaxed and remained elongated.

Note 2 to entry: The string-like elongated structure is sometimes called stringy α structure.

3.3.6
bimodal structure
microstructure composed of equiaxed or elongated α structure embedded in transformed β matrix

3.4 Unwrought products

3.4.1
unwrought product
general term for products obtained by either melting, casting or powder metallurgy processes or a combination thereof

EXAMPLE Ingots for rolling, ingots for extruding, ingots for forging and ingots for remelting.

3.4.2
electrode for remelting
cylindrical or rectangular semi-product formed from titanium sponge and alloying elements or consolidated from recycled and processed scrap, to be remelted once or multiple cycles in a vacuum or in inert gas for at least the final melting

3.4.3
ingot for rolling, extruding and forging
titanium and titanium alloy ingot melted mostly using the vacuum arc remelting (VAR) method applied for at least the final cycle in a vacuum or in inert gas, suitable for rolling, extruding and forging

Note 1 to entry: The melting method is not necessarily limited to VAR. It also includes cases that involve electron beam melting (EBM), plasma arc melting (PAM) and others.

Note 2 to entry: The VAR method is the typical method used for melting titanium and titanium alloys. In this method, the titanium or titanium alloy electrode is dissolved while being consumed itself by an arc generated between a consumable electrode and a water-cooled copper crucible in a vacuum or in an inert gas environment.

Note 3 to entry: The EBM method is also called electron beam cold hearth melting. In this method, charged titanium or titanium alloy is melted in a water-cooled copper hearth using an electron gun and then poured into a mould in a vacuum or in an inert gas chamber.

Note 4 to entry: The PAM method is the method for melting metal using arc discharge generated between the electrode of a plasma torch and the metal, and by using a gas such as argon or helium as the plasma gas. In this method, metal can be melted in an inert gas atmosphere under the environment close to atmospheric pressure.

3.4.4
ingot for remelting
titanium and titanium alloy ingot in a form suitable for remelting after having been processed metallurgically for composition, melted by electron beam melting, vacuum arc remelting and plasma arc melting and other methods applied for at least the final cycle in a vacuum or in inert gas

3.4.5
additive manufacturing product
articles manufactured by 3D metal printing

3.5 Wrought products

3.5.1
wrought product
general term for products obtained by hot and/or cold plastic deformation processes, such as extruding, forging, hot rolling, cold rolling or drawing, either solely or in combination

EXAMPLE Rod/bar, billets, wire, tube, shape/profile, sheet, plate, strip, foils, die forgings, open die forgings.

3.5.2
billet
solid wrought product of uniform cross-section that is above 10 000 mm^2 along its whole length, supplied in straight lengths

Note 1 to entry: The cross-sections are in the shape of circles, ovals, squares, rectangles, equilateral triangles or regular polygons. Products with a square, rectangular, triangular or polygonal cross-section can have corners rounded along their whole length.

3.5.3
rod/bar
solid wrought product of uniform cross-section that is under 10 000 mm^2 along its whole length, supplied in straight lengths.

Note 1 to entry: The cross-sections are in the shape of circles, ovals, squares, rectangles, equilateral triangles or regular polygons. Products with a square, rectangular, triangular or polygonal cross-section can have corners rounded along their whole length.

Note 2 to entry: For rectangular bars:

— the thickness exceeds one-third of the width;

— the term "rectangular bar" includes "flattened circles" and "modified rectangles", of which two opposite sides are convex arcs, the other two sides being straight, of equal length and parallel.

3.5.4
wire
solid wrought product of uniform cross-section along its whole length, supplied in coiled form

Note 1 to entry: The cross-sections are in the shape of circles, ovals, squares, rectangles, equilateral triangles or regular polygons. Products with a square, rectangular, triangular, or polygonal cross-section can have corners rounded along their whole length.

Note 2 to entry: For rectangular wires:

— the thickness exceeds one-third of the width;

— the term "rectangular wire" includes "flattened circles" and "modified rectangles", of which two opposite sides are convex arcs, the other two sides being straight, of equal length and parallel.

3.5.5
wire rod
intermediate unwrought or wrought product for wire

3.5.6
drawing stock
intermediate solid wrought product of uniform cross-section along its whole length supplied in coiled form for drawing

Note 1 to entry: The cross-sections are approximately round, triangular or regular polygonal with dimensions usually exceeding 5 mm.

3.5.7
tube
hollow wrought product of uniform cross-section with only one enclosed hollow space along its whole length, and with a uniform wall thickness, supplied in straight lengths or in coiled form

Note 1 to entry: The cross-sections are in the shape of circles, ovals, squares, rectangles, equilateral triangles or regular polygons. Hollow products with square, rectangular, equilateral triangular or regular polygonal cross-sections, which can have corners rounded along their whole length, are also to be considered as tubes, provided the inner and outer peripheries are concentric and have the same form and orientation.

Note 2 to entry: Tubes can also be formed by piercing trespassing and by forming and joining sheet or strip.

Note 3 to entry: Bent, threaded, drilled, waisted, expanded and cone-shaped hollow products are classified as tubes.

3.5.8
profile/shape
wrought product of uniform cross-section along its whole length, with a cross-section other than rod/bar, wire, tube, sheet, plate or strip, supplied in straight lengths or in coiled form

Note 1 to entry: The profile is either hollow or non-hollow, depending on the form of its cross-section.

a) hollow profile: the cross-section includes either one enclosed hollow space, provided that the cross-section is for other than a tube; or more than one enclosed hollow space;

b) non-hollow profile: the cross-section does not include any enclosed hollow space.

3.5.9
plate
flat-rolled product of rectangular cross-section with uniform thickness over 4,75 mm, supplied in straight lengths (i.e., flat) usually with sheared, sawn or flame-cut/plasma-cut edges or water jet cutting

Note 1 to entry: The thickness does not exceed one-seventh of the width

3.5.10
sheet
flat-rolled product of rectangular cross-section with uniform thickness over 0,20 mm and up to 4,75 mm inclusive, supplied in straight lengths (i.e., flat) usually with sheared or sawn edges or water jet cutting.

Note 1 to entry: The thickness does not exceed one-tenth of the width.

3.5.11
strip
flat-rolled product of rectangular cross-section with uniform thickness equal to and over 0,2 mm, supplied in coils usually with slit edges

Note 1 to entry: The thickness does not exceed one-tenth of the width.

Note 2 to entry: Corrugated, embossed (with patterns, e.g. grooves, ribs, checkers, tears, buttons, lozenges), coated, edge conditioned and perforated products derived from strip are classified as strip.

Note 3 to entry: In some English-speaking countries, "strip" is called "coiled sheet".

3.5.12
foil
flat-rolled product of rectangular cross-section with uniform thickness equal to or under 0,20 mm

Note 1 to entry: In some countries, the term "foil" covers two different products:

— foil: products with lesser thickness;

— thin strip: products with greater thickness.

The dimensional limitations between these two products can vary from country to country.

3.5.13
forging stock
hot-worked intermediate solid wrought product, for example rod/bar or billets, or any other cross-section, suitable for forging

Note 1 to entry: Forging stock can be used as casting stock.

3.5.14
casting stock
cast or hot-worked intermediate solid wrought product suitable for casting purposes

Note 1 to entry: Casting includes investment casting, sand casting, rammed graphite casting, permanent mould casting, pressure die casting as well as centrifuged casting.

3.5.15
forging
wrought product formed by hammering or pressing, usually when hot, between open dies (hand forging) or closed dies (drop or die forging)

3.5.16
blank
piece of titanium of regular or irregular shape taken from a flat wrought product intended for subsequent processing such as bending, stamping or deep drawing

3.5.17
circle
circular blank

3.6 Castings

3.6.1
casting
general term for products at or near the finished shape, formed by solidifying titanium or titanium alloys in a mould

3.6.2
sand/graphite casting
rammed graphite moulding
casting formed in a sand or graphite mould.

3.6.3
permanent mould casting
chill casting
casting formed in a metal mould, where the molten metal is introduced by gravity or a low-pressure feed

3.6.4
pressure die casting
die casting
casting formed in a metal mould, where the molten metal is introduced under high pressure

3.6.5
centrifugal casting
casting formed by centrifugal force in a rotating mould, where the major axis of the casting coincides with the axis of rotation, and the thickness of the casting is determined by the dimensions of the mould and amount of titanium poured

Note 1 to entry: Centrifugal casting is not to be confused with casting under centrifugal pressure.

3.6.6
investment casting
casting method using a ceramic mould formed by wax pattern which is removed before pouring molten titanium and titanium alloys in an inert atmosphere

3.6.7
skull melting technique
technique where the molten metal is contained in a water-cooled copper crucible while confined in vacuum or inert gas chamber

Note 1 to entry: The reactive liquid titanium is prevented from dissolving the crucible due to a solid frozen titanium skull.

Note 2 to entry: Vacuum arc skull melting (VASM) and induction skull melting (ISM)are typical examples of skull melting technology applied to titanium and titanium alloys. These processes involve melting the metal within its own skull using an electric arc or induction coil, which is carried out in a vacuum or under an inert gas environment.

3.6.8
hot isostatic pressing
HIP
post-moulding process to densify castings under temperatures and pressures in an inert atmosphere

Note 1 to entry: Hot isostatic pressing can also be applied to the powder metallurgy process to consolidate and solidify powder.

3.7 Methods of processing and treatment

3.7.1
α-β processing
hot working and annealing in a temperature field below the β-transus temperature, usually the final hot working temperature range

3.7.2
annealing
thermal treatment to soften metal by recrystallization or recovery

3.7.3
ageing
precipitation heat treatment
thermal treatment of an alloy at above room temperature for strengthening by phase transformation and precipitation

3.7.4
β processing
hot working and annealing in a temperature field above the β-transus temperature

3.7.5
bright annealing
thermal treatment in an inert atmosphere for titanium and titanium alloys to prevent scaling or oxidation during annealing

3.7.6
cold working
plastic deformation of titanium and titanium alloys at, for example, room temperature

3.7.7
descaling
procedure to remove the layer of oxide formed on the surface during heating

Note 1 to entry: Shot blasting with steel grit or sand is used for thick-walled cross-sections. A molten salt bath containing an aqueous solution is used for thin-walled pieces, and especially for coils.

3.7.8
diffusion soaking
process in which a metal or an alloy is heated for a period at high temperature, in particular to eliminate or relieve chemical micro-segregation by diffusion

3.7.9
homogenizing
process in which a metal or an alloy is heated for a period at a high temperature, in particular to make the structure uniform at a controlled level

3.7.10
hot working
plastic deformation of titanium and titanium alloys at high temperatures, for example over 700 °C

3.7.11
pickling
procedure to remove α case in an aqueous solution

Note 1 to entry: Prevention against hydrogen pick-up is necessary.

3.7.12
quenching
process of cooling a metal or alloy through contact with a solid, liquid or gas at a rate rapid enough to retain one or all of the soluble constituents in solid solution

Note 1 to entry: Common media used are water, oil or a similar product, or accelerated air.

3.7.13
skin passing
final light cold rolling pass on polished rolls to give a bright finish on coils of titanium and titanium alloys with a controlled influence on the mechanical properties

3.7.14
solution heat treatment
process in which an alloy is heated to a suitable temperature and is held at this temperature long enough to allow soluble constituents to enter into solid solution where they are retained in a super-saturated state upon quenching

3.7.15
solution heat treatment and ageing
STA
heat treatment that includes heating to a temperature at which a solid solution of the alloying elements is formed, then cooling at a rate that maintains this state, followed by precipitation heat treatment

Note 1 to entry: This process increases strength.

3.7.16
stabilising
thermal treatment used to promote stability under service conditions in, for example, dimensions, mechanical properties, structure or internal stress

3.7.17
strain hardening
modification of a titanium structure by cold working, resulting in an increase in strength and hardness, generally with some loss of ductility

3.7.18
stress relieving
annealing method for reducing internal stress by moderate temperatures and controlled smooth cooling

3.7.19
stretch levelling
procedure for smoothing the features of coils by stretching and bending titanium and titanium alloys with a controlled influence to the mechanical properties

3.7.20
superplastic forming
SPF
near-net shape forming method using superplasticity, which is confirmed in several practical alloys with ultra-fine grain microstructure such as Ti-6Al-4V at a high temperature and low strain rate

Note 1 to entry: During tensile testing at a given temperature and low strain rate, the elongation values of these alloys can reach several hundred percent.

3.7.21
diffusion bonding
solid joining process at high temperature, often combined with superplastic forming in order to produce complex components

3.7.22
upset forging
process of swelling the cross section of an ingot or a billet in the α, β or α-β field to control the conversion ratio

3.7.23
additive manufacturing
method to produce 3D objects by stacking layers of melted powder using a high energy beam such as a laser or an electron beam

3.8 Surface condition

3.8.1
α case
oxygen-enriched α phase-stabilised surface layer resulting from elevated-temperature exposure

Note 1 to entry: Because α case has high hardness with poor ductility, α case is commonly removed by pickling or mechanical means.

3.8.2
surface finish
surface condition of final products

Note 1 to entry: The typical finishing surfaces are pickled dull surface, vacuum-annealed bright surface and/or shot-blasted surface, ground surface or machined surface.

3.8.3
surface treatment
processing of surfaces to give products special properties

EXAMPLE 1 Surface treatment for improving corrosion resistance with oxidizing, coating by precious metals and nitriding.

EXAMPLE 2 Surface treatment for improving wear resistance with metallic plating, thermal spraying, oxidizing and deposit welding.

EXAMPLE 3 Surface treatment for design with polishing and anodic oxidation.

EXAMPLE 4 Surface treatment for improving surface conductivity with metal plating by nickel or copper.

3.9 Applications

3.9.1
commercial applications
use in such fields as chemical industry, vehicle and consumer, except use in aerospace and military

3.9.2
non-aerospace applications
use in fields other than the aircraft and space-related equipment fields

3.10 Types of titanium materials and related terms

3.10.1
classification
categorization of titanium materials classified into unalloyed titanium and titanium alloy

Note 1 to entry: For further details, see Annex A.

3.10.2
unalloyed titanium
materials containing a minimum percentage by mass fraction of 98,5 % of titanium with such interstitial elements as carbon, oxygen, nitrogen and hydrogen, and other elements such as iron

Note 1 to entry: Iron is inevitably mixed in due to the use of iron containers during refining and melting.

Note 2 to entry: Other elements other than iron and interstitial elements are not intentionally added and do not exceed the specific limits, unless otherwise specified.

Note 3 to entry: Unalloyed titanium includes high-purity titanium with a purity of N3 or higher, in addition to unalloyed titanium containing trace amounts of the interstitial elements and other elements defined in 3.10.2.

Note 4 to entry: The specific limits for interstitial elements, iron and other elements shall be in accordance with Table A.1.

Note 5 to entry: Exceptions exist in the case of elements that are added in small quantities to enhance corrosion resistance but that do not substantially enhance mechanical properties. Those elements are, for example, palladium, ruthenium, nickel, molybdenum, cobalt, chromium or mixtures thereof.

Note 6 to entry: The maximum mass fraction of alloying elements added to improve corrosion resistance shall be in accordance with Table A.2. The mass fraction of elements other than those specified in Table A.2 shall not exceed 1 %.

Note 7 to entry: ISO 23515 defines the rules for the designation of unalloyed titanium.

3.10.3
titanium alloys
titanium alloy substances in which titanium predominates by mass, over each of the other elements, provided that

a) the mass fraction of at least one of the elements added to improve corrosion resistance greater than the specific limits;

b) the mass fraction of the other elements exceeds 1 %.

Note 1 to entry: The specific limits for elements added to improve corrosion resistance shall be in accordance with Table A.2.

Note 2 to entry: ISO 23515 defines the rules for designation of titanium alloys.

3.11 Titanium grades and compounds

3.11.1
commercially pure titanium
CP titanium
unalloyed titanium grades with a minimum percentage by mass fraction of 98,5 % of titanium including interstitial elements. iron and residual elements not exceeding the specified limits

Note 1 to entry: The mass fraction of limits of interstitial elements, iron and other elements for commercial pure titanium shall be in accordance with Table A.1.

Note 2 to entry: Increasing levels of interstitial elements and iron lead to higher strength, but lower ductility.

Note 3 to entry: For types of commercially pure titanium with different interstitial elements and iron contents, see ISO 23515:2022, 4.2 and ISO 23515:2022, Table A.1.

3.11.2
corrosion resistance-enhanced grades of commercial pure titanium
unalloyed titanium with enhanced corrosion resistance obtained by adding low percentages by mass fraction of palladium, ruthenium, nickel, molybdenum, cobalt and chromium, either singly or in combination with mechanical behaviour comparable to commercially pure titanium

3.11.3
commercially applied titanium alloys
titanium alloys with improved properties due to adding appropriate percentage by mass fraction of alloying elements enhancing mechanical properties, deformability, weldability and corrosion resistance.

3.11.4
special grade titanium alloys
highly alloyed titanium alloys for special use, such as military and aerospace equipment

3.11.5
titanium-base intermetallic compounds
compounds (metal-to-metal) formed by more than two metallic elements with an ordered lattice crystal structure

Note 1 to entry: Different crystal structures from the constituent metallic elements and in the atomic bonding, covalent bonding and/or ionic bonding state are added to the basic metallic bonding. Completely different crystal structures and/or properties originate from the conventional alloy (solid solution). TiAl and Ti_3Al are fundamental titanium base intermetallic compounds and show excellent mechanical properties at high temperatures.

Annex A
(normative)

Dividing line between unalloyed titanium and titanium alloys

It is difficult to draw a line between unalloyed titanium and titanium alloy. It can be more appropriate to classify unalloyed titanium and titanium alloys by differences in the environment in which they are used. For example, materials used in fields where corrosion resistance is the main objective, and materials used in fields where special workability and mechanical properties are required. It may be more appropriate to classify the former as unalloyed titanium and the latter as titanium alloy. In this document, an attempt has been made to draw a numerical line. It is most appropriate to classify materials that intentionally contain more than a certain amount of alloying elements in order to develop special material properties as titanium alloy, and to classify other materials as unalloyed titanium.

Unalloyed titanium materials are classified into two types. One is classified as high-purity titanium material with a purity of mass fraction of 99,9 % or higher. The other is classified as commercially pure (CP) titanium that contains impurity elements such as carbon, nitrogen, oxygen, hydrogen and iron, which are inevitably mixed in during refining, melting and other manufacturing processes, below a certain limit. The content of the impurity elements that are inevitably mixed into CP titanium can be controlled. For example, the strength of CP titanium is remarkably affected by the content of impurities like oxygen and iron. In this sense, impurity elements mixed into CP titanium do not necessarily fall under the category of elements that deteriorate the material properties.

CP titanium is therefore classified as an unalloyed titanium containing a minimum percentage by mass fraction of 98,5 %, including impurity elements and other elements that do not exceed the limits given in Table A.1.

Table A.1 — Limits of interstitial elements, iron and other elements of CP titanium

Element	Limit (% by mass fraction)
Carbon	≤0,08
Oxygen	≤0,40
Nitrogen	≤0,05
Hydrogen	≤0,015
Iron	≤0,50
Each other element	≤0,1
Total other elements	≤0,4

CP titanium that contains palladium, ruthenium, nickel, molybdenum, cobalt and chromium, either singly or in combination at 1 % or less up to the limits given in Table A.2, is classified as corrosion resistance-enhanced grades of CP titanium. This type of CP titanium has enhanced corrosion resistance with mechanical behaviour comparable to CP titanium.

Table A.2 — Maximum mass fraction of non-titanium elements for corrosion resistance-enhanced grades of CP titanium

Element	Limit (% by mass fraction)
Palladium	0,25 %
Ruthenium	0,14 %
Nickel	0,9 %
Cobalt	0,8 %
Chromium	0,2 %
Molybdenum	0,4 %

Titanium alloys are titanium materials that contain 1 % or more of any of the elements listed in Table A.2, or contain alloying elements intentionally added to 1 % or more.

Bibliography

[1] ISO 23515:2022, *Titanium and titanium alloys — Designation system*

[2] Metallography and Microstructures of Titanium and Its Alloys — *ASM Handbook Volume 9, Metallography and Microstructures 2004, pp899-917*

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