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# Light metals and their alloys — Titanium and titanium alloys — Classification and terminology

*Métaux légers et leurs alliages — Titane et alliages de titane — Classification et terminologie*

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# Contents

Page

# Foreword

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ISO 28401 was prepared by Technical Committee ISO/TC 79, *Light metals and their alloys*, Subcommittee SC 11, *Titanium*.

# Light metals and their alloys — Titanium and titanium alloys — Classification and terminology

## 1 Scope

This International Standard gives a classification of titanium and titanium alloys. It also gives terms and definitions in the field of titanium and its alloys.

## 2 Material

2.1
titanium sponge
products of metallic titanium in porous and sponge-like form, which is applied as titanium metal melting stock

NOTE The oxidized titanium ore is first chlorinated to tetrachloride and is condensed and purified and then reduced with magnesium or sodium under the inert atmosphere to produce titanium sponge.

2.2
alloy
metallic substance consisting of a mixture of the basic metallic element (the element predomination by mass) and other elements, such as alloying elements and impurities

2.3
alloying element
metallic or non-metallic elements intentionally added to, or retained by, basic metal for the purpose of giving that metal certain special properties

2.4
impurity
metallic or non-metallic elements present but which are not intentionally added to, or retained by, a metal

2.5
wrought alloy
alloy primarily intended for the production of wrought products by hot and/or cold plastic forming

2.6
casting alloy
alloy primarily intended for the production of castings

2.7
master alloy
alloy intended only for addition to a melt to adjust composition or to control impurities

2.8
heat-treatable alloy
alloy capable of being strengthened by a suitable thermal treatment

2.9
non-heat-treatable alloy
alloy strengthened by cold working only and incapable of being substantially strengthened by thermal treatment

## 3 Specific terms and definitions

3.1
intermediate-strength alloys
alloys with improved properties due to a limited percentage of alloying elements enhancing mechanical resistance and, from case to case, also corrosion resistance

3.2
high-strength standard alloys
alloys with properties similar to the alloy work-horse Ti-6Al-4V (Al ≈ 6 %, V ≈ 4 %), well defined and used with experience

3.3
special alloy grades
high-strength and highly alloyed grades for special use, for example, in military and space equipment

## 4 Unwrought products

4.1
unwrought product
general term for products obtained by melting or casting processes

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

4.2
electrode for remelting
formed from titanium sponge and alloying elements or consolidated from recycled and processed scrap, normally to be remelted finally at least once under a vacuum or in argon

4.3
ingot for rolling
titanium ingot in a form suitable for rolling, melted by EB, VAR, VASM or PM methods applied for at least the final cycle under a vacuum or in argon

4.4
ingot for extruding
titanium ingot in a form suitable for extrusion of bars, tubes and slaps melted by EB, VAR, VASM or PM methods applied for at least the final cycle under a vacuum or in argon

4.5
ingot for forging
titanium ingot in a form suitable for forging, melted by EB, VAR, VASM or PM methods applied for at least the final cycle under a vacuum or in argon

4.6
ingot for remelting
titanium ingot in a form suitable for remelting after having been processed metallurgically for composition, melted by EB, VAR, VASM or PM methods applied for at least the final cycle under a vacuum or in argon

## 5 Wrought products

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

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

NOTE For the classification principles of wrought products, see Annex B.

5.2
billets
solid wrought product of uniform cross-section that is above 10 000 $mm^2$ along its whole length, supplied in straight lengths

NOTE 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 may have corners rounded along their whole length.

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 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 may have corners rounded along their whole length.

NOTE 2 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.

5.4
wire
solid wrought product of uniform cross-section along its whole length, supplied in coiled form

NOTE 1 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 may have corners rounded along their whole length.

NOTE 2 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.

5.5
drawing stock
intermediate solid wrought product of uniform cross-section along its whole length supplied in coils

NOTE The cross-sections are approximately round, triangular or regular polygonal with dimensions usually exceeding 5 mm.

5.6
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 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 may 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 Tubes can also be formed by piercing trespassing and by forming and joining sheet or strip.

NOTE 3 Bent, threaded, drilled, waisted, expanded and cone-shaped hollow products in this form, when derived from tubes as defined above, are classified as tubes.

5.7
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 According to the form of its cross-section, it is called hollow profile or non-hollow profile.

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.

5.8
plate
flat-rolled product of rectangular cross-section with uniform thickness over 5 mm, supplied in straight lengths (i.e. flat) usually with sheared, sawn or flame-cut/plasma-cut edges or water-jet cutting

NOTE The thickness does not exceed one-tenth of the width.

5.9
sheet
flat-rolled product of rectangular cross-section with uniform thickness over 0,20 mm and up to and including 5 mm, supplied in straight lengths (i.e. flat) usually with sheared or sawn edges or water jet cutting

NOTE The thickness does not exceed one-tenth of the width.

5.10
strip
flat-rolled product of rectangular cross-section with uniform thickness over 0,20 mm, supplied in coils usually with slit edges

NOTE 1 The thickness does not exceed one-tenth of the width.

NOTE 2 Corrugated, embossed (with patterns, for example, grooves, ribs, checkers, tears, buttons, lozenges), coated, edge conditioned and perforated products in this general form when derived from strip as defined above are classified as strip.

NOTE 3 In some English-speaking countries, “strip” is called “coiled sheet”.

5.11
foil
flat-rolled product of rectangular cross-section with uniform thickness equal to or less than 0,20 mm

NOTE 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 may vary from country to country.

5.12
forging stock
hot-worked intermediate solid wrought product, for example rod/bar or billets, or any other cross-section, suitable for forging

NOTE Forging stock may also be a cast product, for example, ingot for forging (see 4.5).

5.13
casting stock
cast or hot-worked intermediate solid wrought product, for example, rod/bar or billets, or any other cross-section, suitable for casting

5.14
forging
wrought product formed by hammering or pressing, usually when hot, between open dies (hand forging) or closed dies (drop or die forging)

5.15
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

5.16
circle
circular blank

## 6 Castings

6.1
casting
general term for products at or near the finished shape, formed by solidification of titanium or titanium alloys in a mould

6.2
sand/graphite casting
rammed graphite moulding
casting formed in a sand/graphite mould

6.3
permanent mould casting
chill casting
casting formed in a metal mould, the molten metal being introduced by gravity or low-pressure feed

6.4
pressure die casting
die casting
casting formed in a metal mould, the molten metal being introduced under high pressure

6.5
centrifugal casting
casting formed by centrifugal force in a rotating mould, the major axis of the casting coinciding with the axis of rotation, and the thickness of the casting being determined by the dimensions of the mould and quantity of titanium poured

NOTE Centrifugal casting is not to be confused with casting under centrifugal pressure.

6.6
investment casting
casting method using ceramic shells inert to molten titanium

NOTE The wax pattern has to be removed before pouring the liquid metal into the mould.

6.7
skull melting technique
technique where the molten metal is contained in a water-cooled copper crucible while confined in a vacuum chamber

NOTE The reactive liquid titanium is prevented from dissolving the crucible due to a solid frozen titanium skull.

6.8
hot isostatic pressing
HIP
post-moulding process to densifying castings under temperatures and pressures in an inert atmosphere

## 7 Methods of processing and treatment

7.1
alpha-beta processing
hot working (forging/rolling/annealing) in a temperature field below the beta-transus temperature, usually the final hot-working temperature range

7.2
annealing
thermal treatment to soften metal by removal of strain hardening resulting from cold or hot working by recrystallization or recovery

7.3
ageing
precipitation heat treatment
thermal treatment of an alloy at above room temperature for strengthening by precipitation of soluble constituents from the super-saturated solid solution

7.4
beta processing
hot working (forging/rolling/annealing) in a temperature field above the beta-transus temperature

7.5
beta-transus temperature
temperature above which no alpha phase (hexagonal closed packed crystal configuration) exists

7.6
bright annealing
thermal treatment in a controlled atmosphere to prevent scaling or oxidation during annealing

7.7
cold working
plastic deformation of titanium or alloy at a temperature such that strain hardening occurs

7.8
descaling
procedure to remove the layer of oxide formed on the surface during heating by sand blasting or molten salt bath followed by pickling

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

— molten salt bath: aqueous solution for thin-walled pieces, especially for coils.

7.9
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

7.10
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

7.11
hot working
plastic deformation of titanium or alloy within a temperature range such that strain hardening does not occur

7.12
partial annealing
thermal treatment of cold-worked titanium or alloy to reduce the strength properties to a controlled level

7.13
pickling
procedure to remove the oxygen-rich layer in an aqueous solution followed by shot-blasting for thin-walled pieces

NOTE Prevention against hydrogen pick-up is necessary.

7.14
quenching
process of cooling a metal or alloy from an elevated temperature by contact with a solid, a liquid or a gas at a rate rapid enough to retain one or all of the soluble constituents in solid solution

NOTE Common media used are water, oil or a similar product, or accelerated air.

7.15
skin passing
final light cold-rolling pass on polished rolls giving a bright finish on coils of commercially pure titanium grades with a controlled influence on the mechanical properties

7.16
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 after quenching

7.17
solution heat treated and aged
STA
solution heat treatment followed by artificial ageing (precipitation heat treatment)

7.18
stabilizing
thermal treatment used to promote stability under service conditions in, for example, dimensions, mechanical properties, structure or internal stress

7.19
strain hardening
modification of a titanium structure by cold working, resulting in an increase in strength and hardness, generally with some loss of ductility

7.20
stress relieving
annealing method for reducing internal stress by moderate temperatures and controlled smooth cooling

7.21
stretch levelling
procedure for smoothing the features of coils by stretching and bending of commercially pure titanium grades with a controlled influence to the mechanical properties

7.22
superplastic forming
SPF
forming method using superplasticity which is confirmed in several practical alloys including $\alpha + \beta$ titanium alloys and occurs at a high temperature and low strain rate

NOTE The elongation of these alloys during tensile testing attains several hundred percent.

7.23
upset forging
process of breaking down a cast ingot in the beta-field to control the conversion rate and/or to enlarge an ingot in the transverse direction

## 8 Surface condition

8.1
alpha case
oxygen-, nitrogen- and/or carbon-enriched alpha-stabilized surface layer resulting from elevated-temperature exposure

NOTE Because it has a high hardness with poor ductility, it is commonly removed by pickling or mechanical means.

8.2
surface finish
condition of finishing surface of titanium products

NOTE The typical finishing surfaces are pickled dull surface, vacuum-annealed bright surface and shot-blasted surface.

8.3
surface treatment
surface treatment for achieving special properties

NOTE The special surface treatments are as follows:

a) surface treatment for improving corrosion resistance with oxidizing, coating by precious metals and nitrizing;

b) surface treatment for improving wear resistance with metallic plating, thermal spraying, oxidizing and deposit welding;

c) surface treatment for design with polishing and anodic oxidation;

d) surface treatment for improving surface conductivity with metal plating by Ni or Cu.

## 9 Applications

9.1
commercial applications
generally commercialized use, except aerospace, military and special use

9.2
non-aerospace applications
industrial, military and special use, except aerospace use

## 10 Abbreviations for titanium melting methods

EB Electron Beam (re)melting

VAR Vacuum Arc Remelting

VASM Vacuum Arc Skull Melting

PM Plasma Melting

## 11 Classification of titanium and titanium alloys

### 11.1 General

Titanium and titanium alloys are classified as follows (for further details, see Annex A).

### 11.2 Unalloyed titanium

Unalloyed titanium is metal with a minimum mass fraction of 98,5 % of titanium, provided that, unless otherwise specified, the mass fraction of any residual element does not exceed the limit specified in Table 1.

**Table 1 — Limits**

| | |
|---|---|
| Each residual element | $\leqslant$ 0,1 % |
| Total residual elements | $\leqslant$ 0,4 % |

Exceptions exist in the case of elements added in small quantities for the purpose of enhancing the corrosion resistance but not substantially enhancing the mechanical properties.

Those elements are, for example, palladium, ruthenium, nickel, molybdenum, cobalt, chromium or mixtures of some of these elements.

The mass fraction of elements other than those specified in Table 2 shall not exceed 1 %.

**Table 2 — Maximum mass fraction of non-titanium elements for the purpose of corrosion-resistance enhancement in the case of commercially pure titanium grades**

| | |
|---|---|
| Pd | 0,25 % |
| Ru | 0,14 % |
| Ni | 0,9 % |
| Co | 0,8 % |
| Cr | 0,2 % |
| Mo | 0,4 % |

### 11.3 Titanium alloys

Titanium alloys are metallic 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 is greater than the limit specified in Table 2, or

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

# 12 Titanium grades and compounds

## 12.1 Commercially pure titanium (CP titanium)

The principal difference among these grades is the levels of interstitial elements and iron. Increasing levels of these elements lead to higher strength, but lower ductility.

## 12.2 Corrosion-resistance-enhanced grades of CP titanium

The grades with enhanced corrosion resistance are obtained by adding low percentages of palladium, ruthenium, nickel, molybdenum, cobalt and chromium, either singly or in combination, with the limits according to Table 2. The mechanical behaviour is comparable to the standard commercially pure (CP) grades.

## 12.3 Titanium-base intermetallic compounds

These alloys (metal-to-metal compound) are formed by more than two metallic elements having the crystal structure of an ordered lattice. 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 titanium and titanium alloys

Owing to the fact that, in the whole field of non-ferrous metals, materials now exist having alloying elements of mass fractions lower than 1 %, which would cause difficulties in fixing the dividing line between an unalloyed metal and an alloy at a certain percentage, for example 99,0 % (mass fraction), this principal question was carefully studied by a joint meeting of representatives of the Customs Co-operation Council (CCC) and of ISO/TC 18, *Zinc and zinc alloys*, ISO/TC 26, *Copper and copper alloys*, and ISO/TC 79, *Light metals and their alloys*, in Brussels in February 1974. It was shown that the previous dividing line of 99,9 % (mass fraction) could no longer be maintained as the classification principle in the Customs Co-operation Council Nomenclature (CCCN), because, in view of technical developments, some exceptions have to be made.

On the other hand, a purely scientific definition of an alloy could not be accepted because, in many cases, the specification of the material in question is unknown. In any case, it is necessary to avoid the possibility that a material, whether standardized or not, could be classified as titanium as well as a titanium alloy, depending on its actual content of alloying elements.

It was therefore suggested that the classification should be based on a table indicating the limiting values for elements, so that the material could be classified on the basis of the specification to which it is supplied or, in case of doubt, on the result of an analysis of the material in question.

It was generally agreed that such a table is technically and economically correct and that it represents a modern concept of a classification principle, being based on the actual requirements of both metallurgical and commercial practice.

Concerning the dividing line between titanium and titanium alloys, it should be recalled that the table showing limiting values is a classification principle to be applied in case of doubt only. It is not considered as a specification according to which products can be ordered, supplied or tested.

# Annex B
(normative)

# Explanatory notes concerning the definitions of wrought products

## B.1 Classification principles

In order to simplify the definitions and to avoid difficulties which might be caused by further technical developments, all references to sizes have been deleted, with the exception of rolled flat products, i.e. the definitions are to be based on the forms of delivery only.

## B.2 Dividing lines

### B.2.1 Rod and bar: wire

Rod and bar is generally supplied in straight lengths and wire is supplied in coils.

### B.2.2 Tube: hollow profile

The dividing line between “tube” and “hollow profile” shall be drawn not only by the uniform wall thickness, but also by an “only one enclosed hollow space” for the tube. It was agreed that the term “hollow bar” should not be used.

### B.2.3 Plate: sheet: strip: foil

The commercially used dividing lines are as follows:

— plate: $>$ 5 mm thick;

— sheet/strip: thickness $>$ 0,2 mm to $\leqslant$ 5 mm;

— foil: thickness $\leqslant$ 0,2 mm.

### B.2.4 English term “drawing stock”

Taking into account different manufacturing processes, for example, extruding, hot rolling, continuous casting with subsequent hot rolling, the term “drawing stock” for the intermediate product was selected as the preferred term to replace the term “wire rod”.

a) Drawing stock: this term was derived by analogy with “forging stock”, in order to express that this intermediate product is intended to be drawn.

b) Wire rod: this term, which is used in some countries, has been rejected on the basis of terminology principles; “wire” and “rod” are terms for two different products, which shall not be combined to name a third product.

### B.2.5 Cast stock

Cast stock is used for electrodes for casting purposes, investment casting, sand casting, rammed graphite casting, as well as centrifuged casting.

# Alphabetical index

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