TITANIUM AND Ti-ALLOYS

Subject: Materials Science

MSc presentation
Széchenyi István University

Dr. Zsoldos Ibolya

1. INTRODUCTION:

The Titanes (Titans) were six Greek gods, sons of Uranus (the god of the Sky) and Gaia (the goddess of the Earth), who were known about their extremely huge strong.

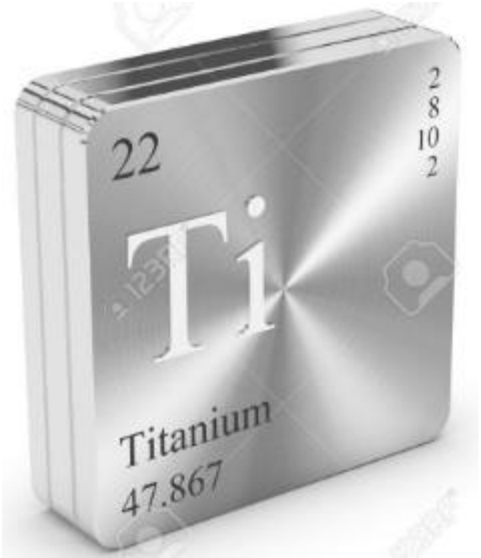
The chemical element of titanium was called by the Titanes, and this name has reality according to the properties of the titanium.

Oceanus, god of the sea, member of the Titans (6 brothers)
Statue of the Trevi Fountain, Rome

1. INTRODUCTION:

Titanium is **lightweight, strong, corrosion resistant** and **abundant in nature**.

Titanium and its alloys possess **tensile strengths** from 210 **to 1400 MPa**, which are equivalent to those strengths found in most of steels.
The **density of titanium is only 56 percent that of steel**, and its **corrosion resistance compares well with that of platinum**.
Of all the elements in the earth's crust, titanium is the **ninth most plentiful**.



Titanium has a **high melting point 1725°C**. This melting point is approximately 220°C above the melting point of steel and approximately 1100°C above that of aluminium.

TITANIUM EXTRACTION

Although titanium is the **fourth most common metal element in the earth's crust** (behind aluminium, iron, and magnesium), **production of titanium metal is extremely sensitive to contamination**, **particularly by oxygen**, which accounts for its relatively recent development and **high cost**.

The **main ores** used in the primary production of titanium are **ilmenite**, which accounts for about 90% of production, and **rutile**, which accounts for the remaining 10%. Both types of these ores contain **TiO_2 together with more or less contaminants**.

ilmenite

TITANIUM EXTRACTION

Titanium **can't be extracted by** reducing the ore using carbon as **a cheap reducing agent**. The problem is that **titanium forms a carbide, TiC**, if it is heated with carbon, so we don't get the pure metal that we need. The **presence of the carbide makes the metal very brittle**.

That means that **we have to use an alternative reducing agent**. In the case of titanium, the reducing agent is either **sodium or magnesium**. **Both of these would, of course, first have to be extracted from their ores by expensive processes.**

rutile

TITANIUM EXTRACTION

The ore of the titanium is first converted into titanium tetrachloride, which is then reduced to titanium using either magnesium or sodium:

Conversion of TiO_2 into $TiCl_4$: the ore rutile (impure titanium dioxide) is heated with chlorine and coke at a temperature of about 1000°C.

The chemical reaction is: $\mathbf{TiO_2 + 2Cl_2 = TiCl_4 + O_2}$

Other metal chlorides are formed as well because of other metal compounds in the ore. Very **pure liquid titanium tetrachloride can be separated from the other chlorides by fractional distillation under an argon or nitrogen atmosphere, and is stored in totally dry tanks**.

TITANIUM EXTRACTION

Reduction of the titanium tetrachloride: $TiCl_4$ can be **reduced using either magnesium or sodium**.

Titanium tetrachloride vapour is passed into a **reaction vessel** containing **molten magnesium** in an **argon atmosphere**, and the temperature is increased to **about 1000°C**. The **reduction process is very slow**, taking about **2 days**, followed by **several more days of cooling**.

The chemical reaction is: $\mathbf{TiCl_4 + 2Mg = Ti + 2MgCl_2}$

All the **magnesium chloride dissolves in the water present**, and the remaining **titanium is processed further to purify it**.

TITANIUM EXTRACTION

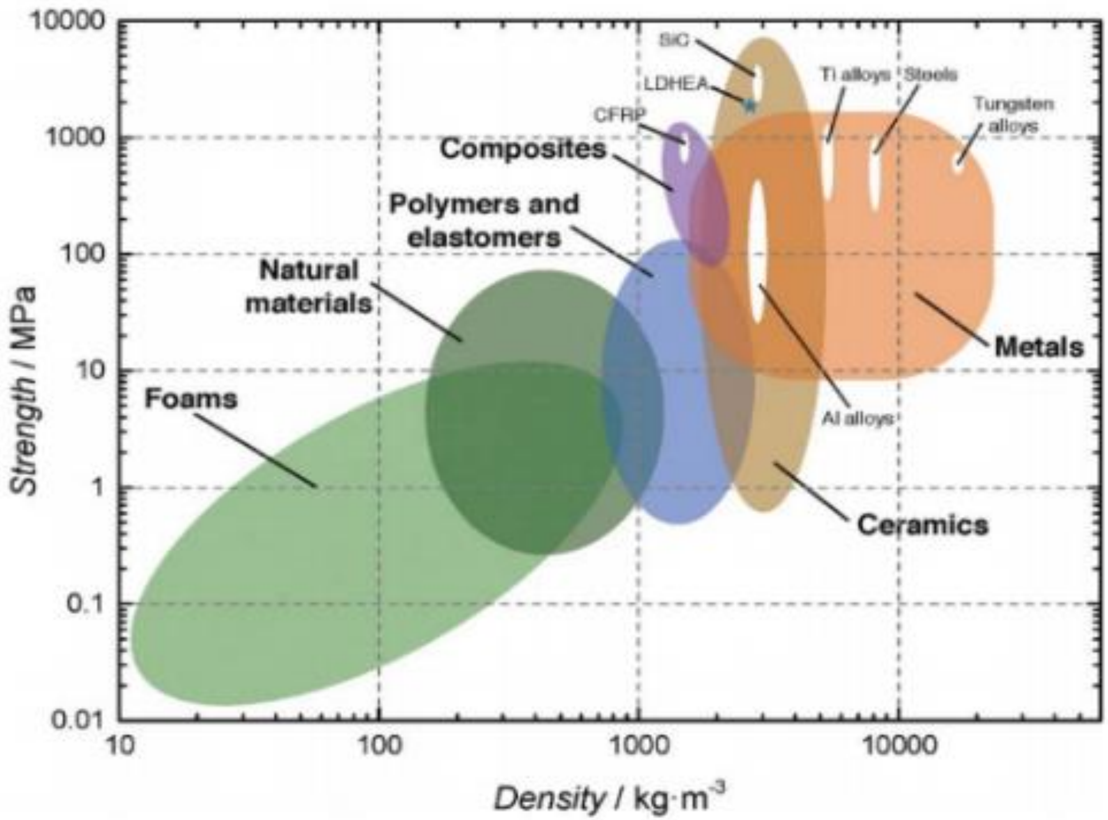
The **world production of titanium is very small**, hundreds of thousands of tonnes, which really is small, compared to steel at 800 million tonnes per annum (Table 1). **80% of all the titanium produced is used in the aerospace industries.**
Car suspension springs could easily be made of titanium with a great reduction in weight but **titanium is not available in the large quantities needed and certainly not at the price required for automobile applications**. The target **price** for titanium **needs to be reduced to about 30%** of its current value for serious application in mass-market cars.

	Mg	Al	Ti	Fe
Density / $g\,cm^{-3}$	1.74	2.7	4.51	7.87
Modulus / GPa	45	70	120	210
Specific Modulus / $GPa\,cm^3\,g^{-1}$	25.9	26	26	27
Melting Temperature / °C	650	660	1670	1535
Crystal Structure (300 K)	h.c.p.	c.c.p.	c.p.h.	Cubic–I
Production per annum /tonnes	5×10^5	2×10^7	5×10^5	8×10^8
Energy Cost / $MW\,h\,tonne^{-1}$	??	70	130	15
Relative Cost	7.5	3.7	9	1.0

Polmear (3rd edition), Journal of Metals. 54 (2002) 42–48

TITANIUM: GENERAL PROPERTIES

In the figure **comparison of strength and density of different materials families** can be seen.

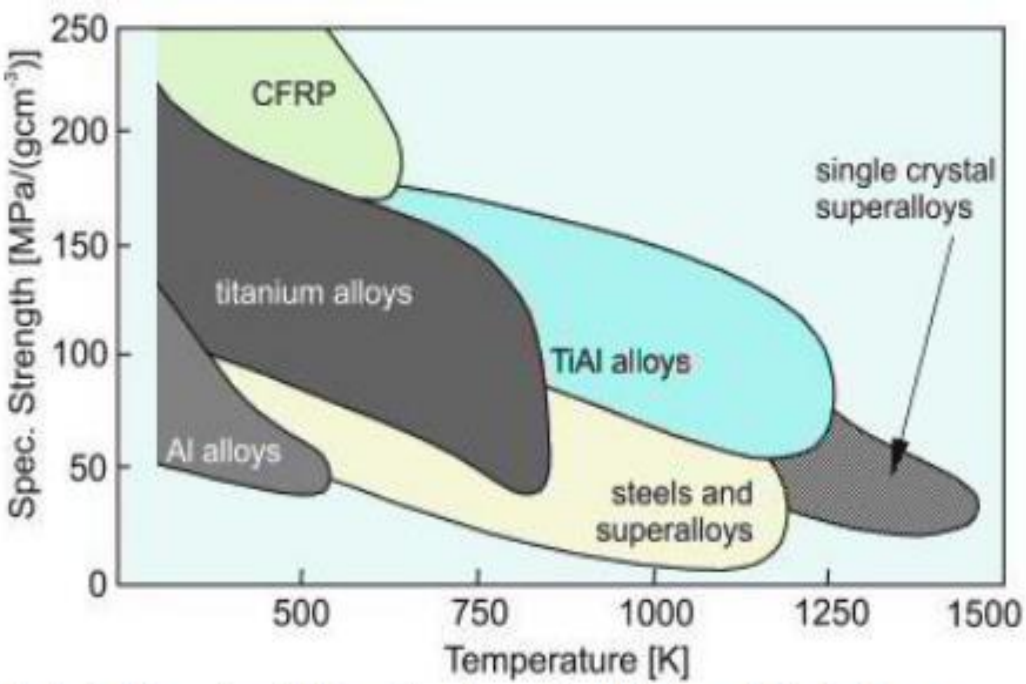


Ashby plot of strength vs. density for engineering materials. Credit: Elsevier 2010 / Khaled M. Youssef et. al.

TITANIUM: GENERAL PROPERTIES

In the figure **comparison of strength, density and heat resistant properties of different materials families** can be seen.

In general, it can be said that **titanium alloys are applicable** in case of such parts where **high strength** and **low density** are required **at high temperature.**



Mechanical Properties of Titanium Alloys (image from: Titanium and Titanium Alloys. Fundamentals and Applications. eds. Leyens, Peters)

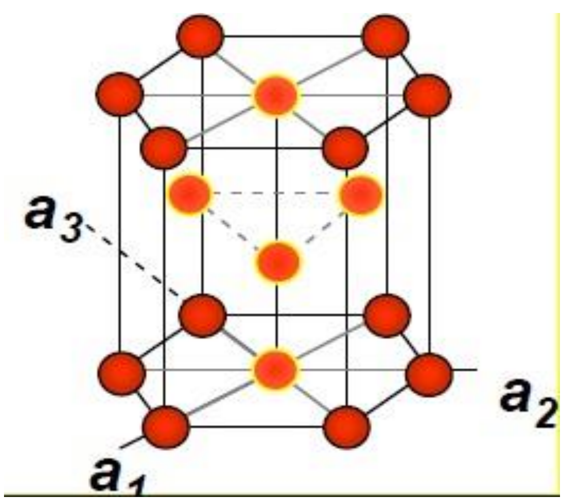
PURE TITANIUM

Pure titanium has **excellent resistance to corrosion** and is used widely in the **chemical industries**. There is a **passive oxide film**, which makes it particularly resistant to **corrosion in oxidising solutions**. The corrosion resistance can be **further improved by adding palladium** (0.15 wt%).

PURE TITANIUM

The **crystal structure** of titanium **at ambient temperature** and pressure is **close-packed hexagonal (α)** with a c/a ratio of 1.587.

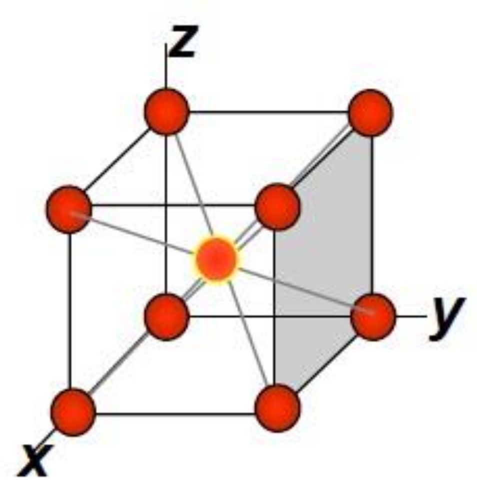
At about 890°C, the titanium undergoes an allotropic transformation to a body-centred cubic β phase, which remains stable to the melting temperature.



allotropic transformation

→

882,3 ^{0}C



ALLOYING ELEMENTS OF TITANIUM

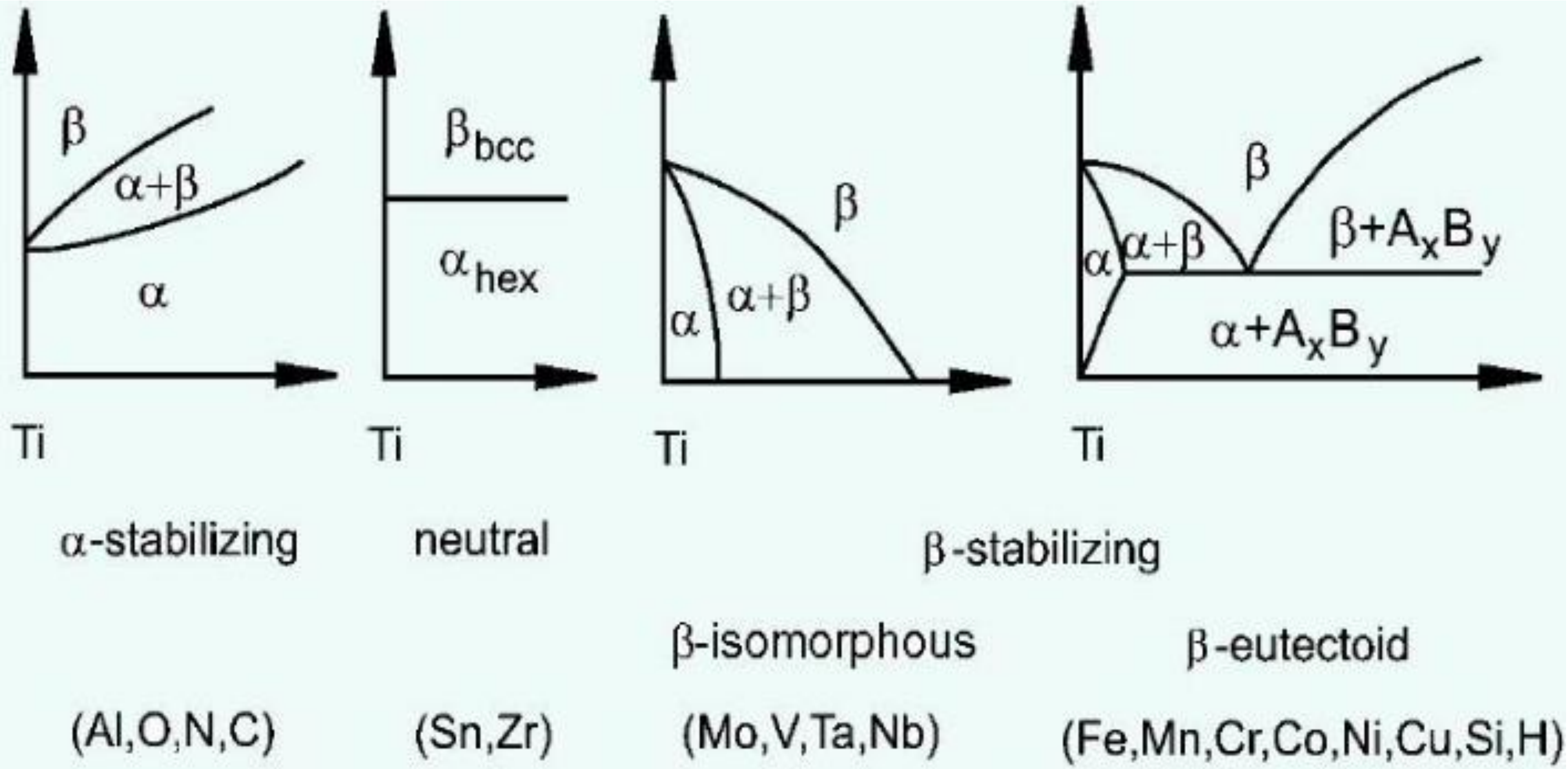
The alloying elements can be **categorised according to their effect on the stabilities of the α and β phases** . Thus:

- **Al, O, N and Ga are all α–stabilisers.**
- **Mo, V, W and Ta are all β–stabilisers (β isomorphous stabilisers).**
- **Cu, Mn, Fe, Ni, Co and H are also β–stabilisers but form the eutectoid.** The eutectoid reaction is frequently sluggish (since substitutional atoms involved) and is suppressed.
- **Zr, Sn and Si are neutral elements.**

Molybdenum and vanadium have the largest influence on β-stability and are common alloying elements. Tungsten is rarely added due to its high density. Cu forms $TiCu_2$ which makes the alloys age–hardening and heat treatable; such alloys are used as sheet materials. It is typically added in concentrations less than 2.5 wt% in commercial alloys.

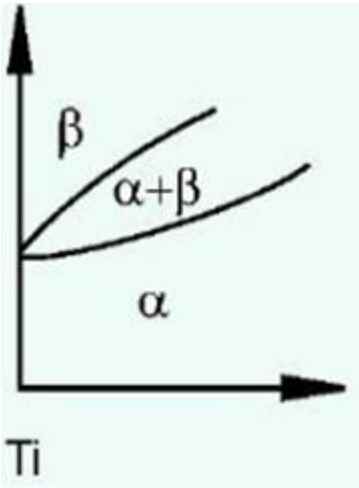
ALLOYING ELEMENTS OF TITANIUM

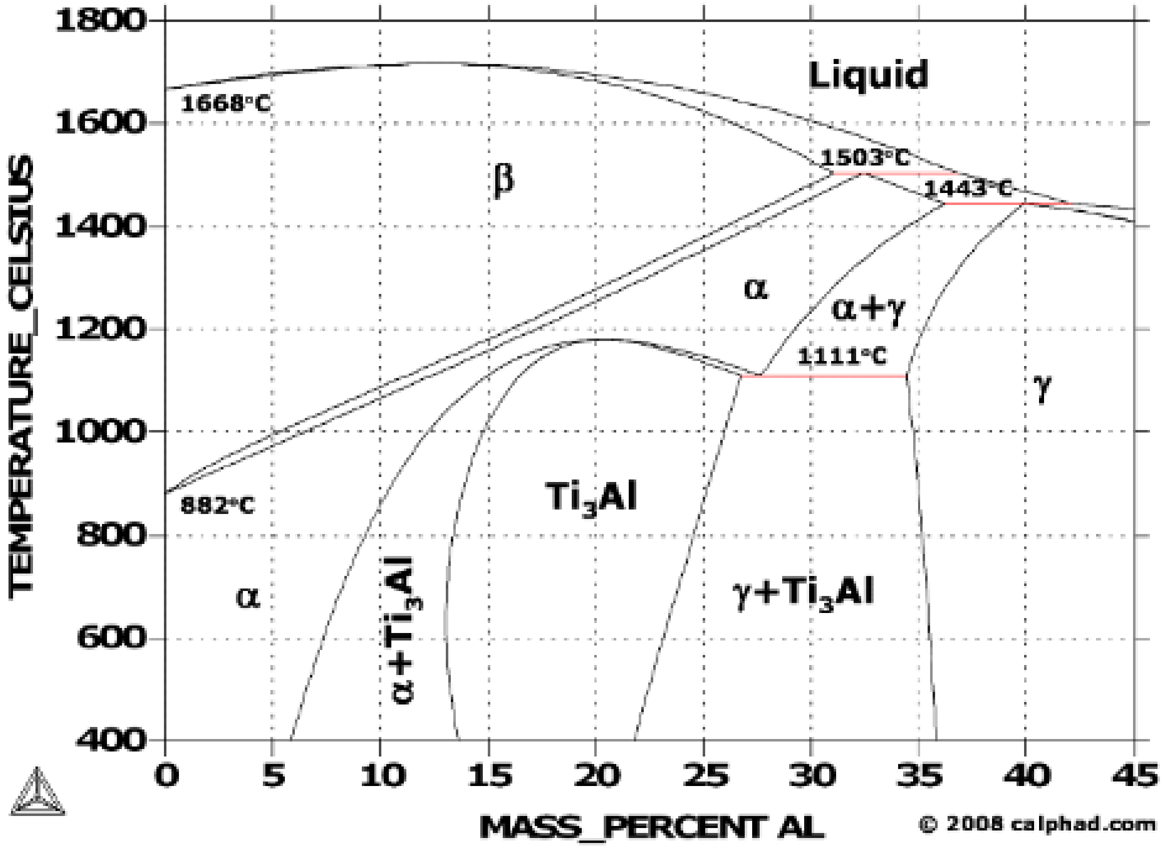
Classification:



ALLOYING ELEMENTS OF TITANIUM

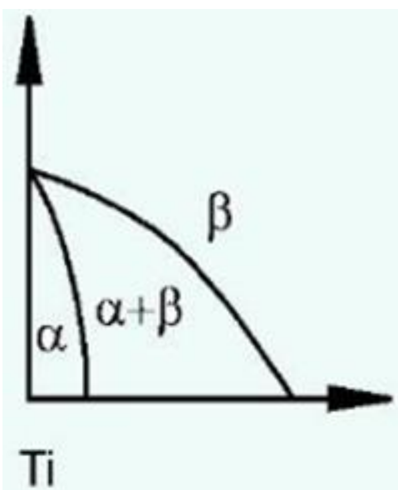
Example for α–stabiliser:
Ti-Al phase diagram:

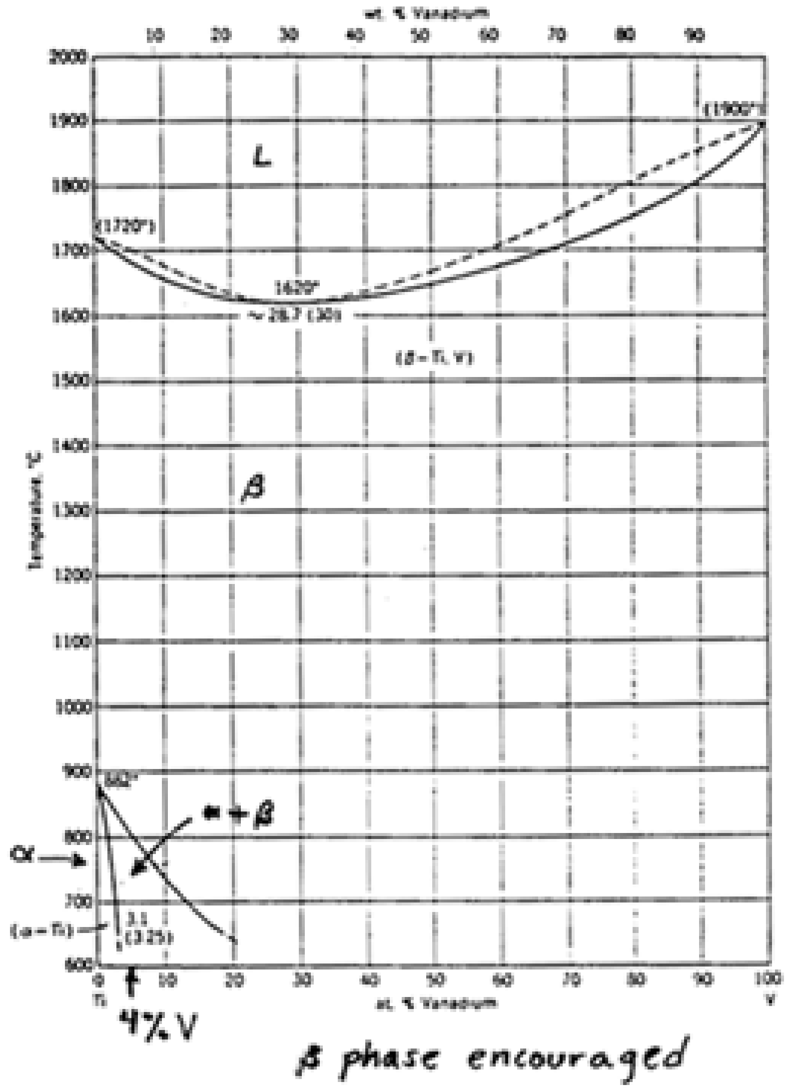




ALLOYING ELEMENTS OF TITANIUM

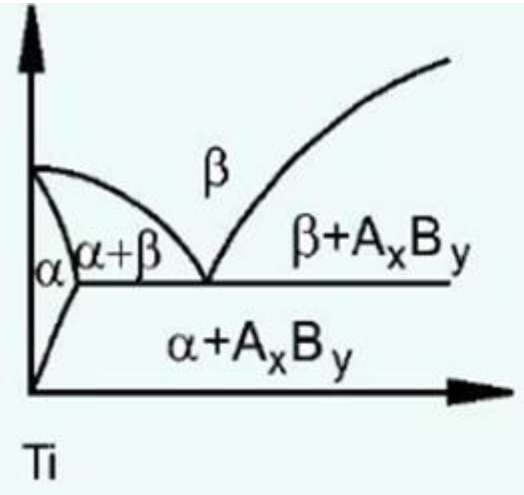
Example for β-isomorphous stabiliser:
Ti-V phase diagram:

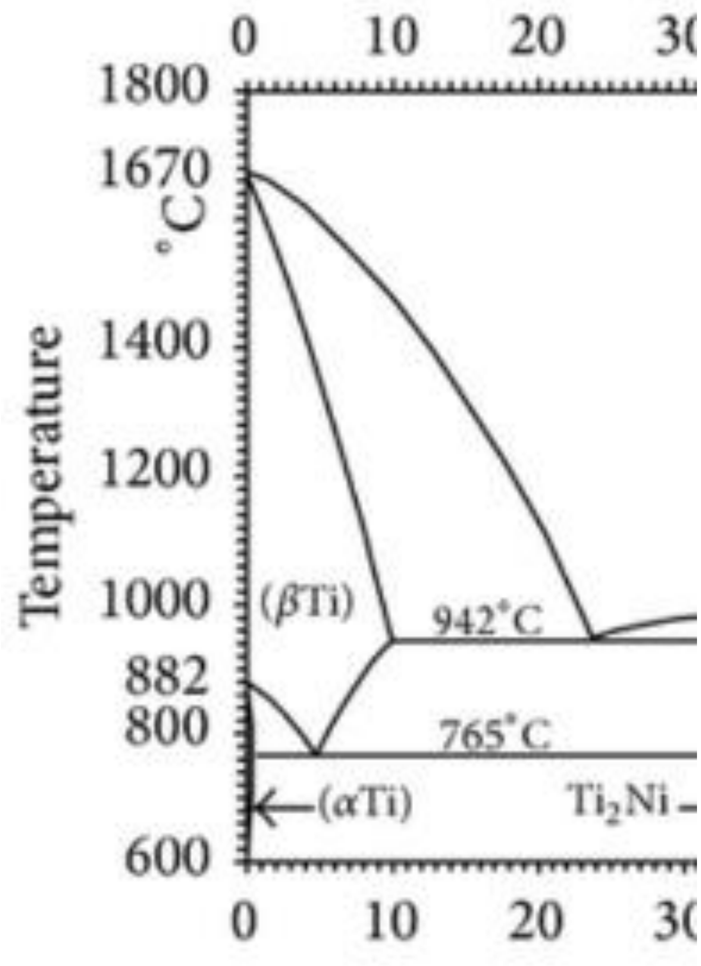




ALLOYING ELEMENTS OF TITANIUM

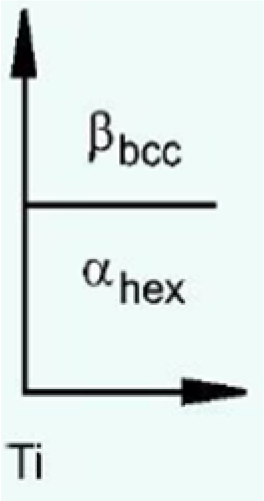
Example for β–eutectoid stabiliser:
Ti-Ni phase diagram:

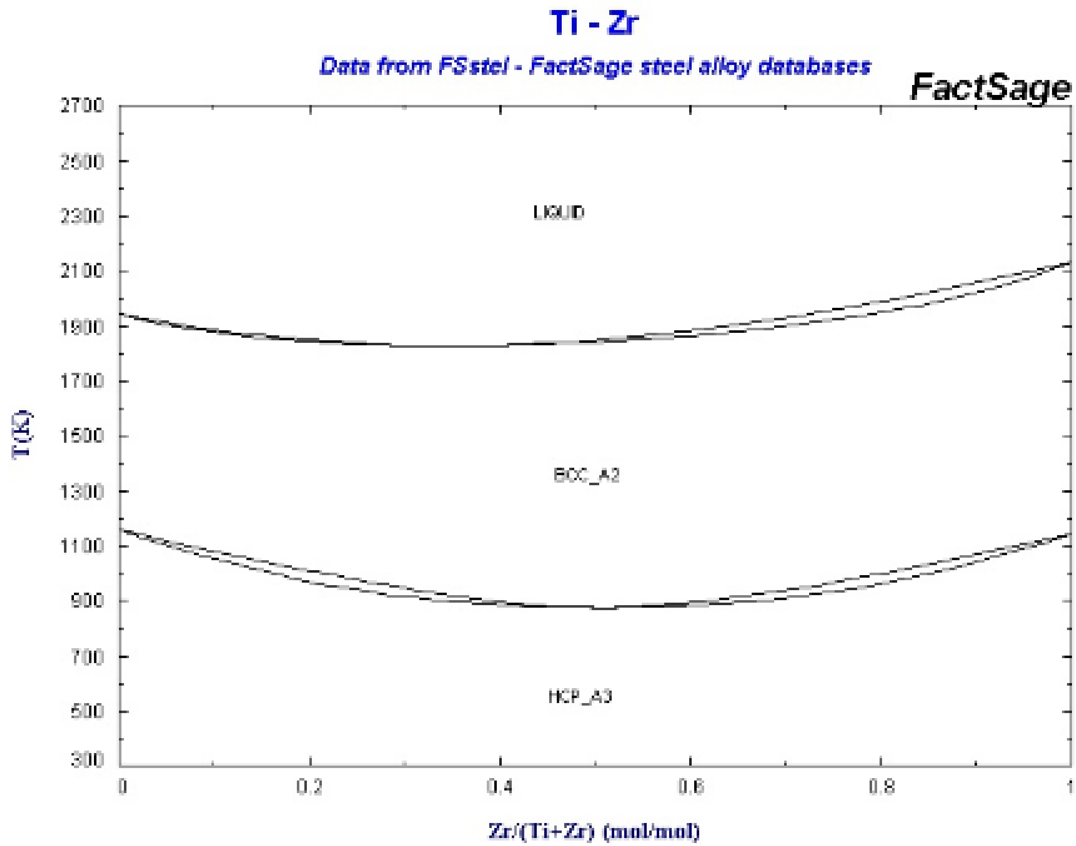




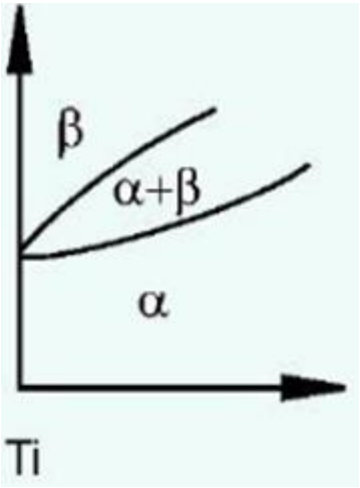
ALLOYING ELEMENTS OF TITANIUM

Example for the neutral case:
Ti-Zr phase diagram:





ALLOYING ELEMENTS OF TITANIUM



α-Stabilisers

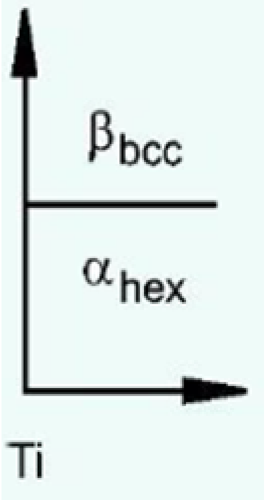
α-stabilisers are more soluble in the α-phase and raise the β transus temperature.

Oxygen is added to pure titanium to produce a range of grades having **increasing strength** as the oxygen level is raised.

Aluminium is the only other α–stabiliser **used commercially and is a major constituent of most commercial alloys**. It is a **very effective α–strengthening element** at ambient and elevated temperatures **up to about 550°C**.

The **low density of aluminium** is an additional advantageous feature but the **amount** that can be added **is limited** because of the formation of a brittle titanium-aluminium compound at aluminium contents exceeding about 8% by weight.

ALLOYING ELEMENTS OF TITANIUM



Neutral alloying elements:

The α–phase is also strengthened by the addition of **tin (Sn) or zirconium (Zr)**.

These metals have **appreciable solubility in both α– and β–phases** and as their addition **does not markedly influence the transformation temperature** they are normally classified as **neutral additions**.

As with aluminium, the beneficial ambient temperature hardening effect of tin and zirconium is retained at elevated temperatures.

ALLOYING ELEMENTS OF TITANIUM

β-Stabilisers

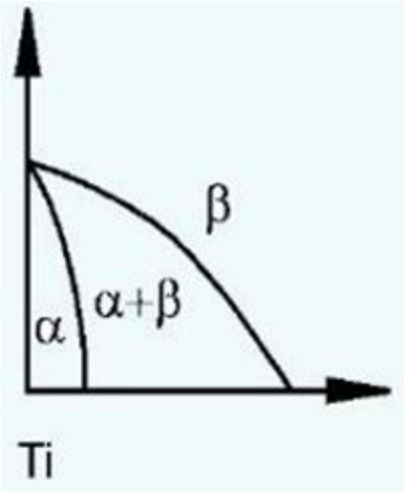
Elements that **depress the transformation temperature**, readily **dissolve in and strengthen the β–phase** and exhibit **low α–phase solubility** are known as β–stabilisers.

They can be divided into **two categories according to their** constitutional **behaviour with titanium:**

- **β-isomorphous elements,**
- **β-eutectoid elements.**

ALLOYING ELEMENTS OF TITANIUM

β-Isomorphous Elements

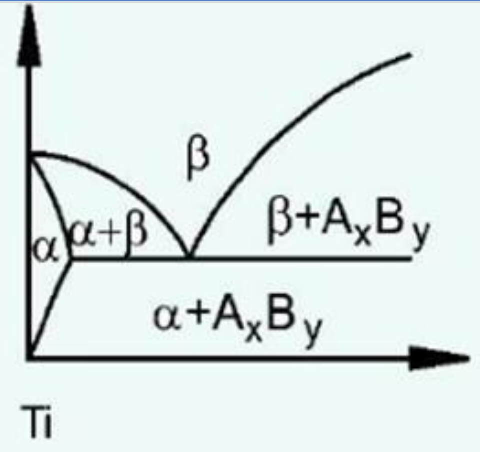


β–isomorphous elements exhibit **complete mutual solubility with β–titanium**.

Increasing addition of the solute element **progressively depresses the transformation temperature** to give the characteristic phase diagram.

Molybdenum and vanadium are the most important β–isomorphous elements, while niobium and tantalum have also found application in some alloys.

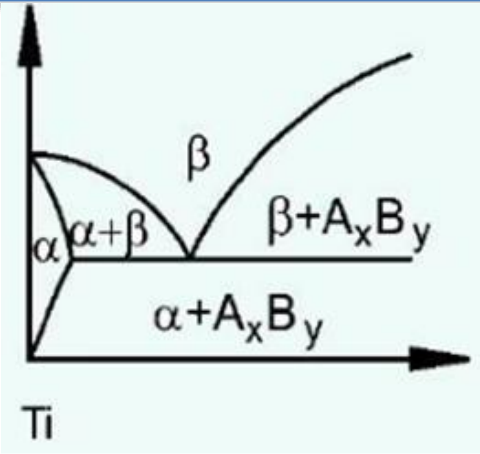
ALLOYING ELEMENTS OF TITANIUM



β-Eutectoid Elements

β–eutectoid elements have **restricted solubility in beta titanium** and form intermetallic compounds by **eutectoid decomposition of the β–phase**. Elements of the β–eutectoid type can be further subdivided into sluggish and active elements. Commercially important metals in the sluggish category are iron, chromium and manganese. **Eutectoid decomposition** of β–phase in the titanium-iron, titanium-chromium and titanium-manganese systems **is so slow that intermetallic compound formation does not occur** during normal commercial fabrication and heat treatment or during service and, therefore, **for practical purposes** the behaviour of iron, chromium and manganese **can be likened to that of β–isomorphous elements**.

ALLOYING ELEMENTS OF TITANIUM



β-Eutectoid Elements

In contrast, **copper and silicon form active eutectoid systems** where below the eutectoid temperature the β–phase decomposes to α and intermetallic compounds **within commercially acceptable times**.

As a result, controlled precipitation of the intermetallic compounds can be utilised to enhance the strength of titanium alloys containing appropriate concentrations of silicon or copper.

ALLOYING ELEMENTS OF TITANIUM

β-stabilisers

In addition to strengthening the β–phase,
β–stabilisers have **two other important advantages** as alloying constituents:

- β–titanium has an inherently **lower resistance to deformation than the α–modification** and therefore elements which increase and stabilise the β–phase tend to **improve alloy fabricability during both hot and cold working operations**.
- Addition of sufficient β–stabiliser to titanium compositions also confers a **heat treatment capability** which permits **significant strengthening** to be achieved by controlled decomposition of β–phase to α–phase during the heat treatment process.

Ti-ALLOYS AND THEIR HEAT TREATMENT

There are three structural types of titanium alloys:

- **Alpha Ti-alloys** generally are non-heat treatable, weldable, common properties are: medium strength, good creep strength, good corrosion resistance.
- **Alpha-Beta Ti-alloys** are heat treatable, common properties are: good forming properties, medium to high strength, good creep strength.
- **Beta Ti-alloys** are heat treatable and readily formable, common properties are: very high strength, low ductility.

Ti-ALLOYS AND THEIR HEAT TREATMENT

The system of the titanium alloys:

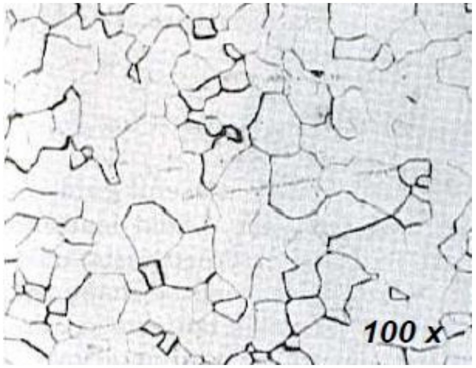
	Alpha Ti-alloys			Alpha-Beta Ti-alloys	Beta Ti-alloys	
	pure (CP) α-Ti-alloys	α-Ti alloys	near α-Ti alloys		Metastable β-Ti alloys	Stable β-Ti alloys
Alloying elements	only α-stabilisers: α<1%	only α-stabilisers: α<9%	α<9%, ~β<2% (about)	α<9%, ~β<10-15% (about)	~15%<β<25% (about)	~β>25% (about)
Phases (strengthening phases)	α, α'	α, α', $α_2$	α, α', $α_2$, β (small amount)	α, α', $α_2$, β (large amount)	metastable β	stable β

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

Alpha-titanium alloys have **further three sub-types:**

- **commercially pure (CP) titanium-**,
- **α-Ti** and
- **near α-Ti** alloys.

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys



COMMERCIALLY PURE (CP) Ti-ALLOYS:

- **The total amount of the alloying elements**
- of the CP Ti-alloys is between **0.1-1%**.
- They contain **only α-stable alloying elements**, mainly oxygen which improve the strength, and the other elements present impurities. Consequently, their **microstructure consists of only grains of α-solid solution**.
- Their **strength is medium high** and so this group is the **less expensive type** of the Ti-alloy family.
- However, their **corrosion resistance to nitric acid, moist chlorine is outstanding**.
- **0.2% Pd addition extends the corrosion resistance in hydrochloric acid (HCl), sulphuric acid (H_2SO_4) and phosphoric acid (H_3PO_4)**, as well.

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

COMMERCIALLY PURE (CP) TI-ALLOYS

This type of the Ti-alloys is applied as the material of airframes, heat exchangers, chemicals, marine, surgical implants.

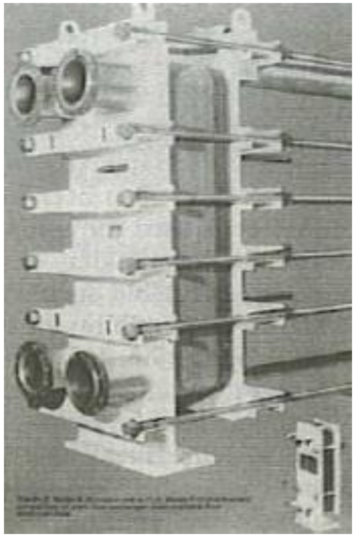
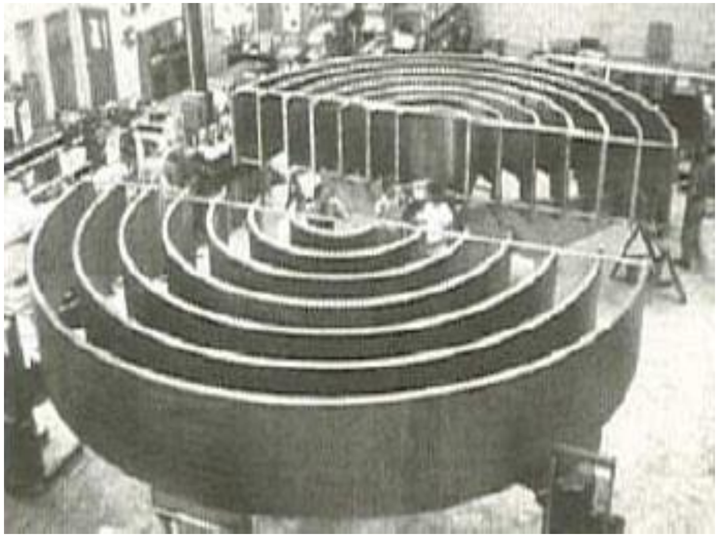


Plate and frame heat exchanger



Large structure used in bleaching section of pulp and paper

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

HEAT TREATMENT OF THE CP-TI ALLOYS

After **annealing from the β-field (cooling with normal rate**) an α-phase having hexagonal crystal structure develops.

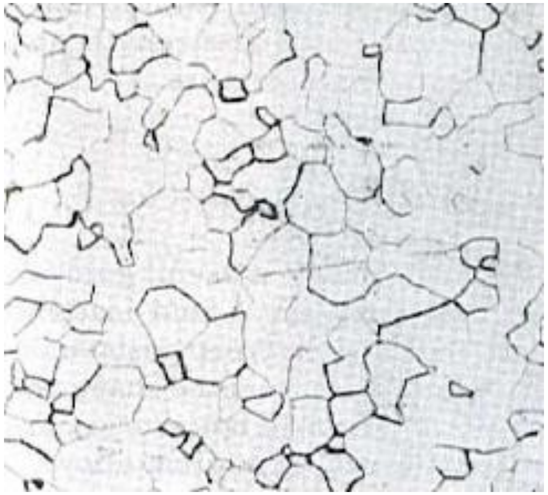
After **quenching from the β-field (rapid cooling) also martensite phase (α'-phase) develops** near the α-phase.

Martensite phase means a supersaturated solid solution in case of the Ti-alloys, as well.

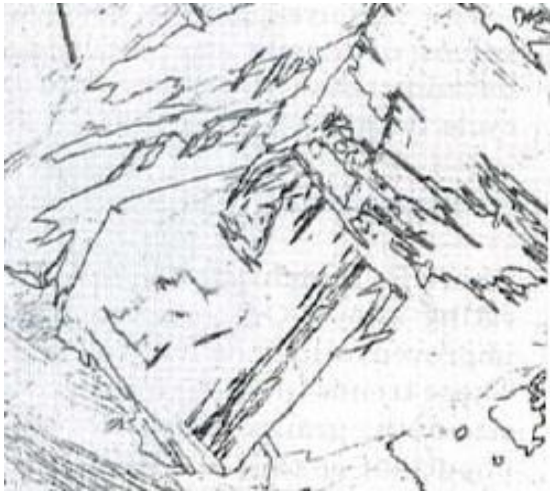
This **martensite phase is stable (in time) at room temperature**, however the **strength increase is much smaller than for** martensite phase of the **steels**.

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

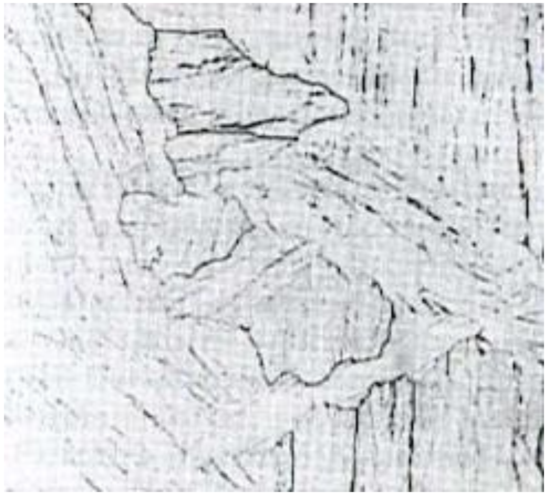
HEAT TREATMENT OF THE CP-TI ALLOYS



Annealed structure.



Quenched from β-field.

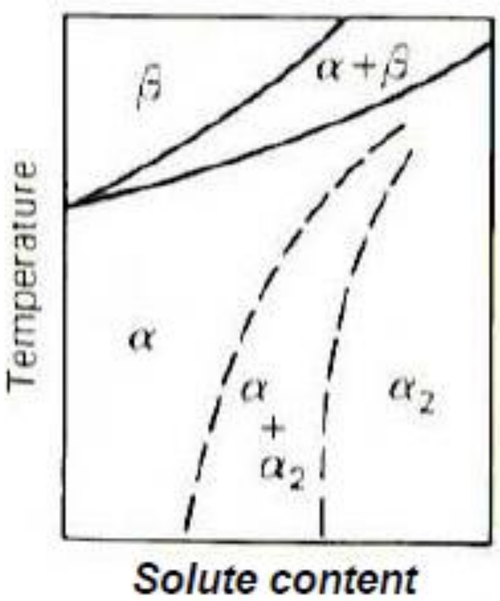


Air-cooled from β-field.

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

α-Ti-ALLOYS:

- The α-titanium alloys contain **only α-stable alloying elements**, as well.
- The **total amount of the alloying elements** of the α-Ti-alloys is between **1-9%**. The amount of α-stabilisers should not exceed 9% **to prevent embrittlement**.
- **Al is the main alloying element**, which provides **solid solution strengthening**. O and N present as impurities give interstitial hardening.
- **5-6% Al** can lead to a finely dispersed, **ordered phase – α_2-phase** - which is coherent to lattice. **α_2-phase is advantageous** in the microstructure **regarding the strength**, but it is **deleterious regarding the ductility**.



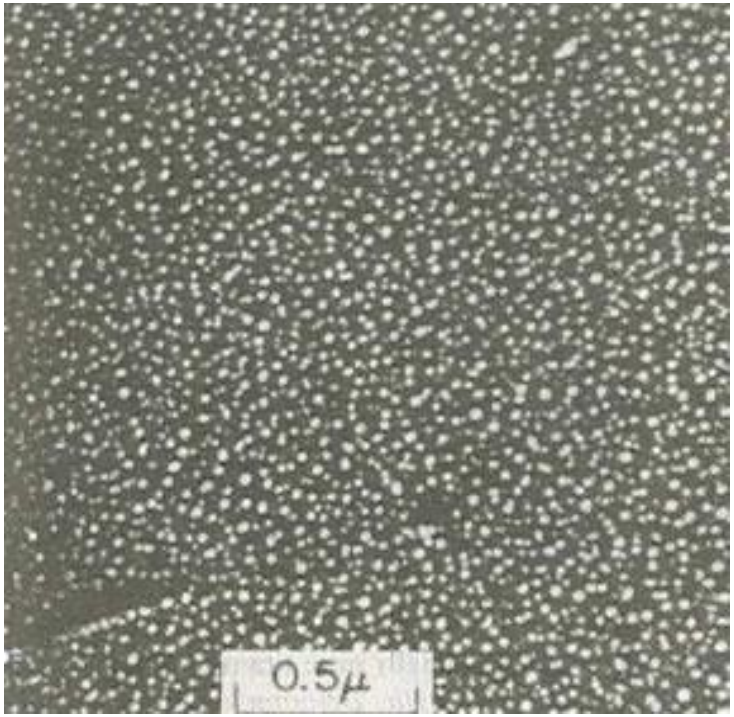
Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

α-Ti-ALLOYS:

The figure shows the **characteristic pattern of the α_2-phase**.

In the microscopic image the **fine precipitations of the chemical compound of Ti_3Al (white colour)** can be seen clearly.

Sn (tin, stannum) and **Zr** (zirconium) are also added in small amount to stabilise the α-phase and improve the strength.



Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

HEAT TREATMENT OF THE α-Ti-ALLOYS

The possibilities and the **heat treatment cases are the same as for CP Ti-alloys**. Also, parallel with the appearance of the α_2-phase an additional strengthening can be reached **by quenching** and forming **martensite phase in the structure**.

α-Ti alloys have a **moderate strength** which depend on the Al and/or O contents.

The **aluminium reduces the density**, as well.

These alloys are **readily weldable**, they have a **good oxidation resistance upto 600 ^oC**.

Aircraft engine compressor blades, **sheet-metal parts** are characteristic in the applications, however, **material of cryogenic vessels** used **at -250 ^oC** are these alloys, as well.

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

NEAR α-Ti-ALLOYS:

Near the α-stabilisers, the so called „near α-Ti alloys" contain a **smaller amount of β-stabilisers (1-2%)**.

The **amount of the α-stabilisers is larger than for CP and α-Ti alloys, in order to keep the good ductility**.

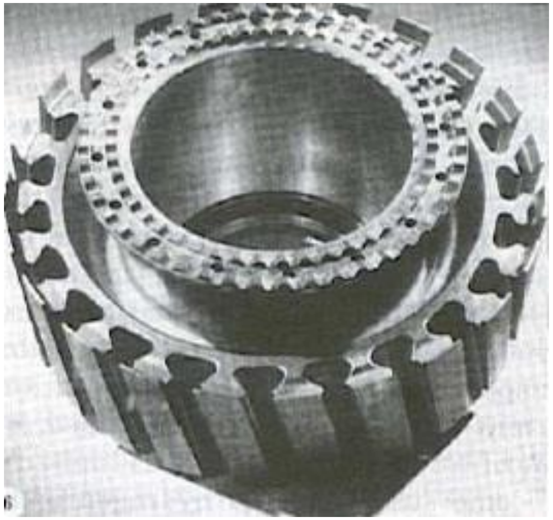
As β-stabilisers **molybdenum and vanadium** are used, so these alloys **become heat treatable to β-phase**, as well.

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

NEAR α-Ti-ALLOYS:

- **Moderately high strength** at room temperature and **relatively good ductility** (~15%).
- **High toughness** and **good creep strength at high temperatures**.
- **Good weldability**.
- **Good resistance to salt-water** environment.

Characteristic examples of the near α-Ti alloys, Ti-8Al-1Mo-1V és a Ti-6Al-2Sn-4Zr-Mo alloys are applied in **airframe** and **jet-engine parts requiring high strength at 450 °C, good creep and toughness**.



Forged compressor disc made from near α-Ti alloy

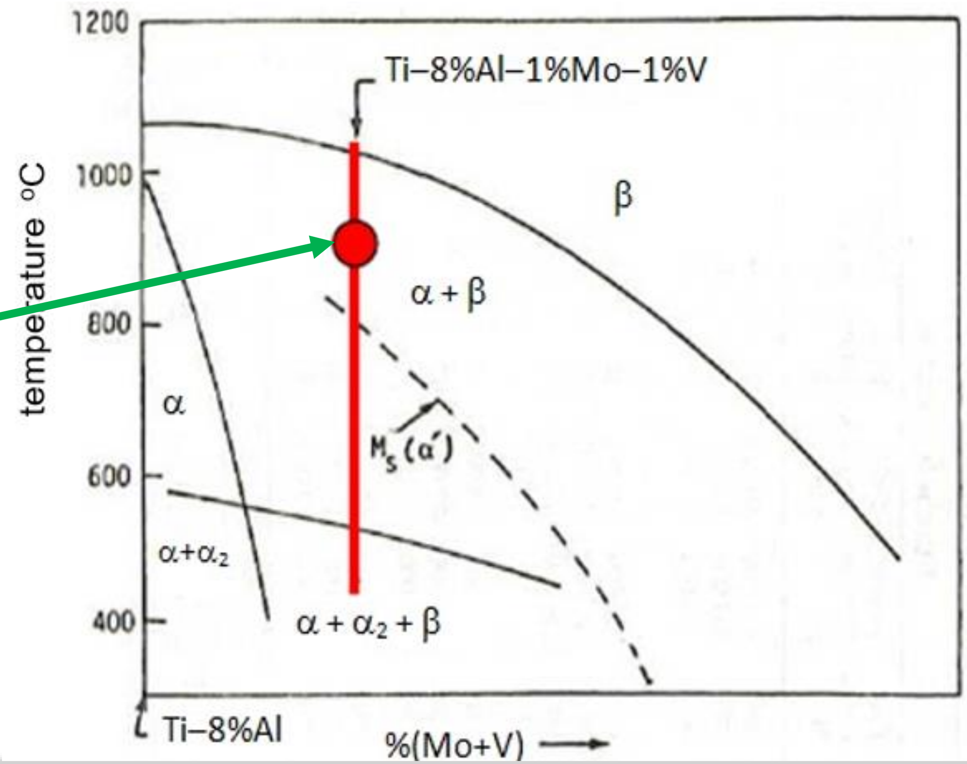
Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

HEAT TREATMENT OF THE NEAR α-Ti-ALLOYS

Two essential types of the heat treatment are applied.

The first type is a **heat treatment from lower temperature**.

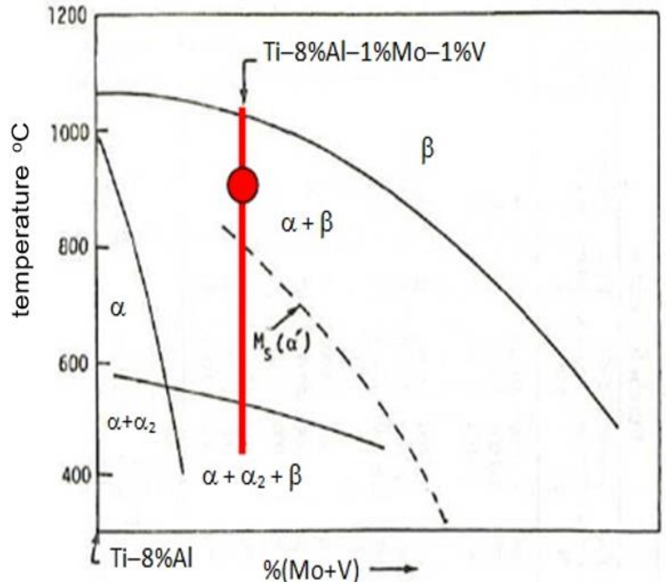
The alloy is **heated to the α+β field**, where the alloy obtains around equal amount of α and β phases.



Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

HEAT TREATMENT OF THE NEAR α-Ti-ALLOYS

Air-cooling gives primary α-phase and **Widmanstätten α** formed by nucleation and growth from the β-phase. **In case of faster cooling the β transforms into martensitic α' which gives higher strength**.



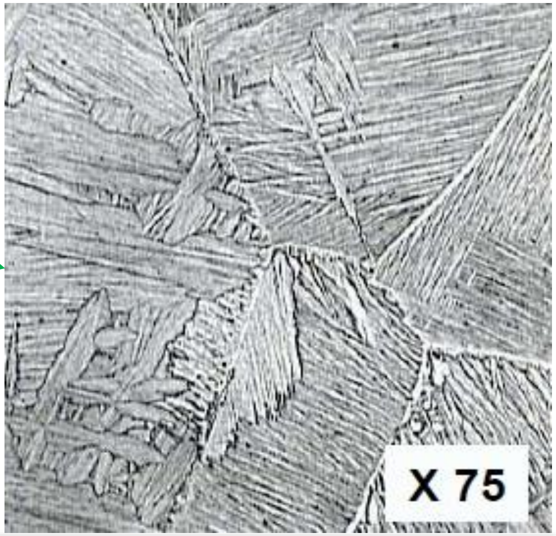
Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

HEAT TREATMENT OF THE NEAR α-Ti-ALLOYS

The second type is a **heat treatment from higher temperature**: the alloy is **heated to the β-field**.

Quenching from the β-phase field produces **laths of martensitic α',** which are **delineated by thin films of β-phase**.

Air-cooling from the β-phase field gives a **basket weave structure** of **Widmanstätten α-phase delineated by β-phase**.

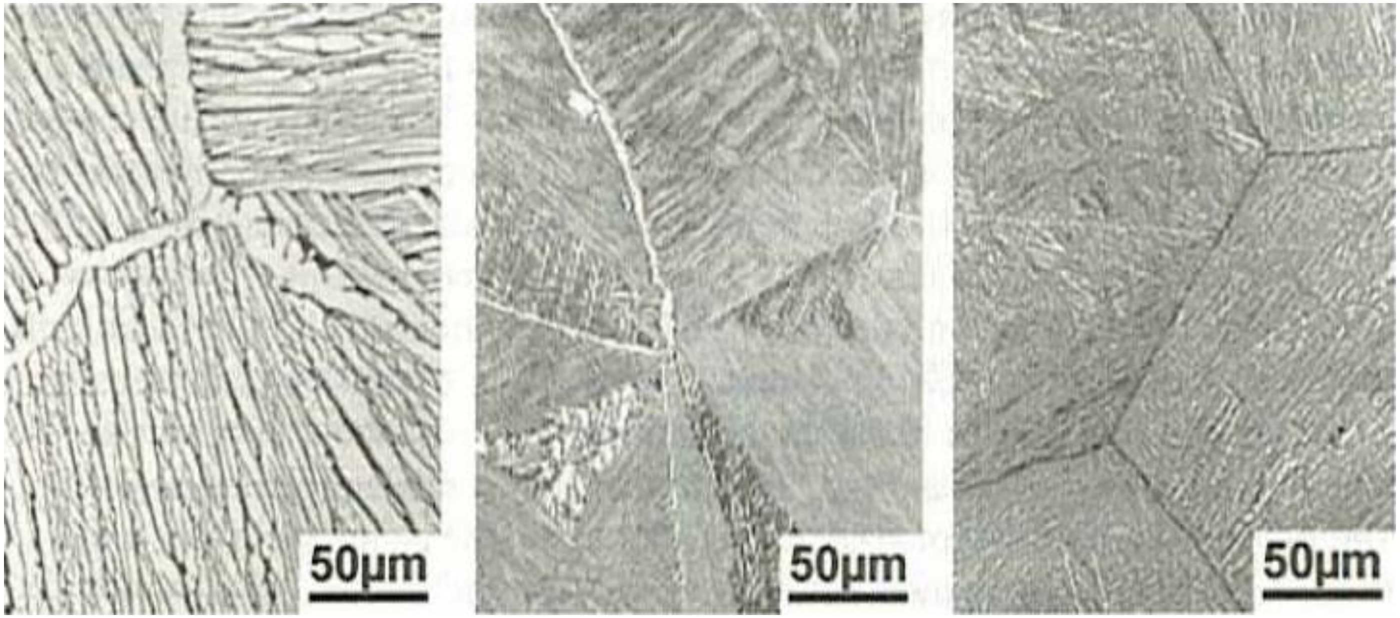


Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-titanium alloys

HEAT TREATMENT OF THE NEAR α-Ti-ALLOYS

The second type is a **heat treatment from higher temperature**: the alloy is **heated to the β-field**.

The lamellar structure becomes finer with the increasing of the cooling rate:



1^0C/min 100^0C/min 8000^0C/min

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-Beta Ti-alloys

Alpha-beta titanium alloys contain **both of α- and β-phase**.

α-stabilisers are used with 4-6%.

β-stabilisers (3-15%) are used to allow the **β-phase to retain at room temperature** after quenching from β or α+β phase field.

Improved strength and formability are characteristic in comparison to α -Ti alloys.

Ti-6Al-4V is the most widely commercially used type.

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-Beta Ti-alloys

Properties and applications of the α-β-Ti alloys

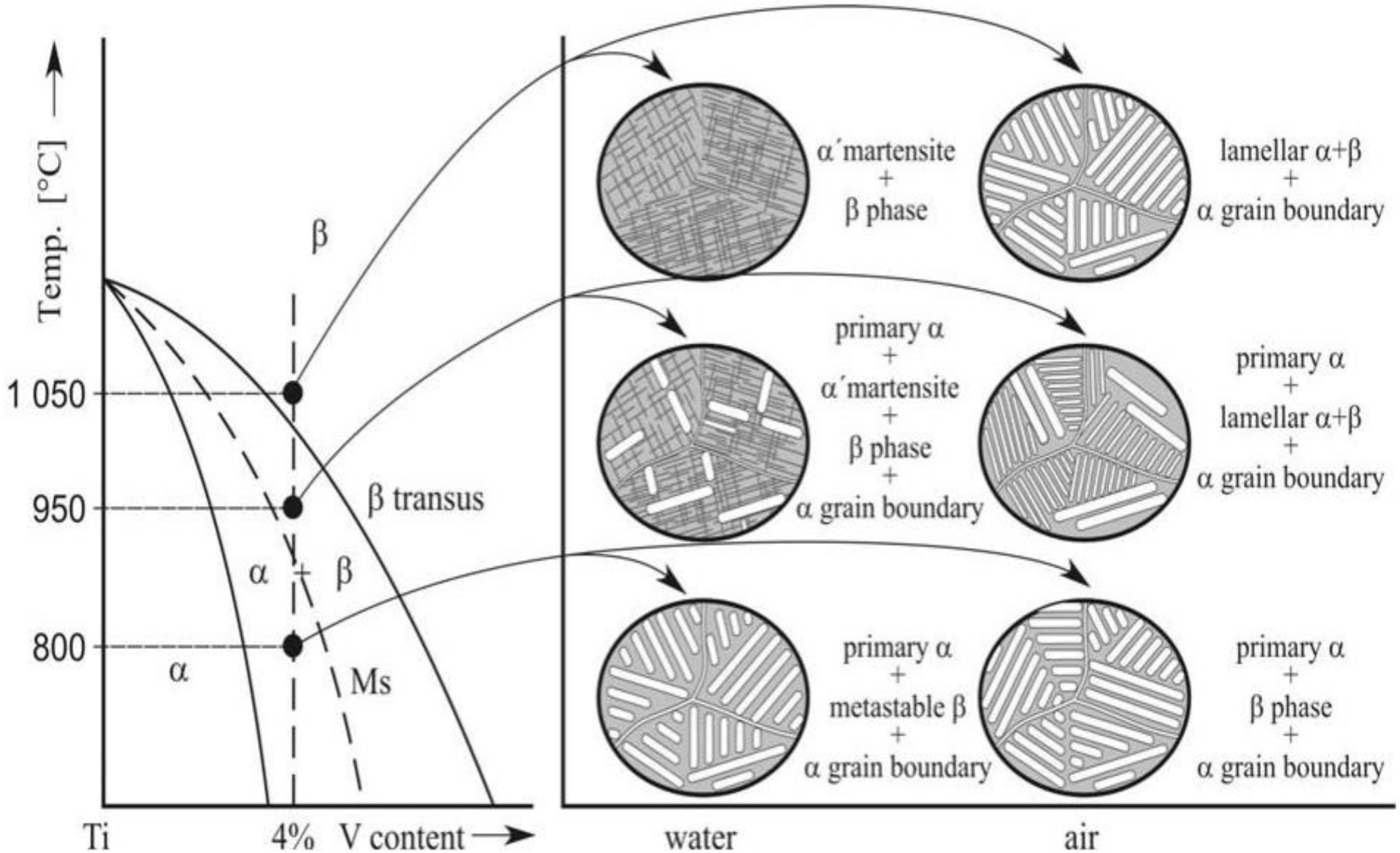
Ti-6Al-4V is the most widely used titanium alloy. It features **good machinability and excellent mechanical properties**. The Ti-6Al-4V alloy offers the best all-round performance for a variety of weight reduction applications in aerospace, automotive and marine equipment. Ti-6Al-4V also has **numerous applications in the medical industry**. **Biocompatibility** of Ti-6Al-4V is excellent, especially when direct contact with tissue or bone is required.

Ti-6Al-4V is typically used for:

– **Direct Manufacturing** of parts and prototypes for **racing and aerospace industry**,
– Biomechanical applications, such as **implants and prosthesis**,
– **Marine applications**,
– Chemical industry,
– **Gas turbines**.

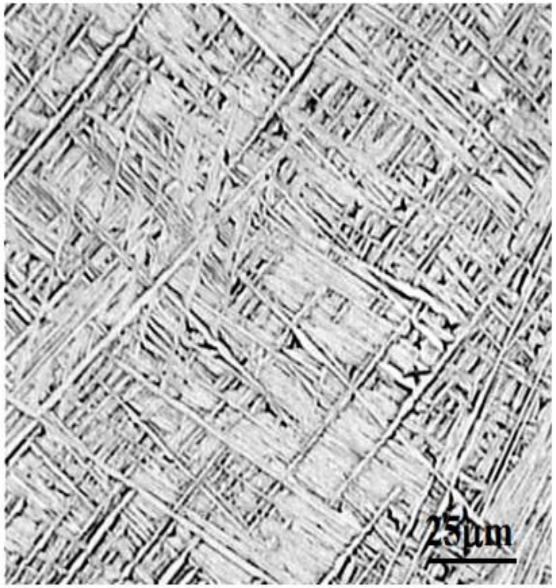
Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-Beta Ti-alloys

HEAT TREATMENT OF THE NEAR α-Ti-ALLOYS: in the **example of the Ti-6Al-4V**



Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-Beta Ti-alloys

HEAT TREATMENT OF THE NEAR α-Ti-ALLOYS: in the **example of the Ti-6Al-4V**
The microstructure of **as-cast Ti6Al4V alloy** is shown in the figure. The structure of the alloy is **two-phased**, consists of **α and β solid solutions**. The **lamellae** of the **α-phase (light)** are relatively regular and are mutually connected in a form of **basket weave**. Between these phases are thin areas of **β-phases (dark).**
By the boundaries of the prior β-grains α-phase was formed which "delimits" these grains (grain boundary α).

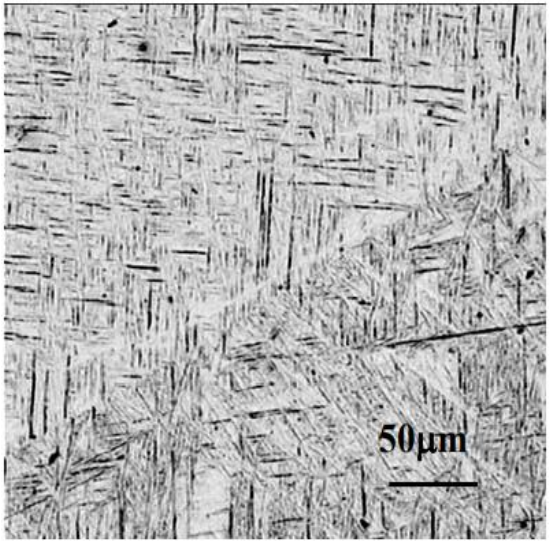


Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-Beta Ti-alloys

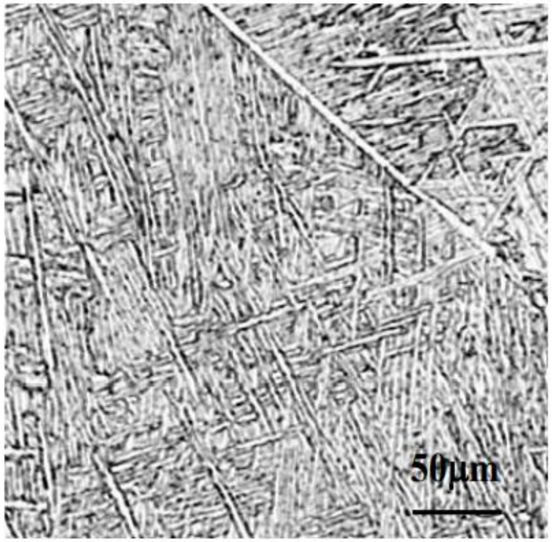
HEAT TREATMENT OF THE NEAR α-Ti-ALLOYS: in the **example of the Ti-6Al-4V**
The microstructures after the heat treatment **from the β-field** (1050 °C) are shown in the figures.

As a result of **fast cooling in water** an acicular (**needle-shaped) α' martensite** structure was formed: **left figure**.

Heat treatment at 1050 °C **by air cooling** leads to the **typical lamellar α + β structure**: **right figure**.



water cooling

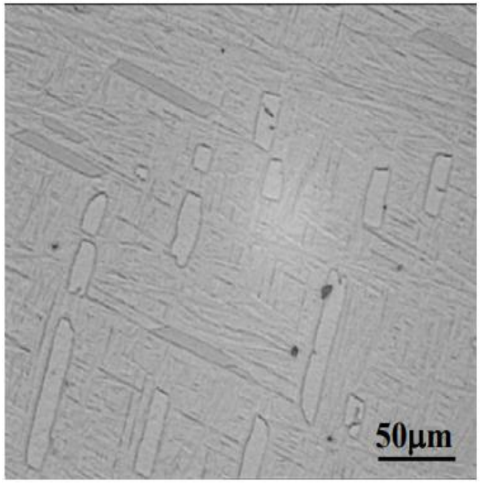


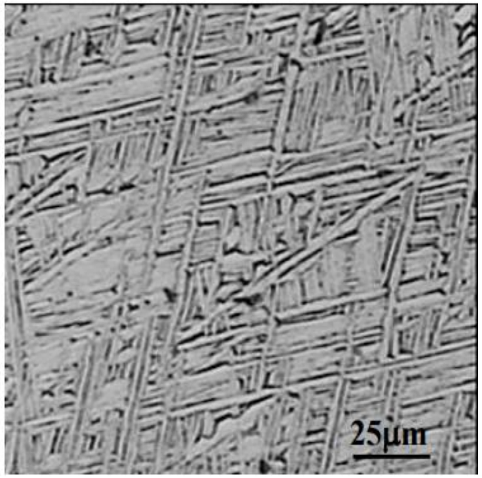
air cooling

Ti-ALLOYS AND THEIR HEAT TREATMENT: Alpha-Beta Ti-alloys

HEAT TREATMENT OF THE NEAR α-Ti-ALLOYS: in the **example of the Ti-6Al-4V** Cooling **in water from the α+β-field** (950 ^{o}C) produces a microstructure which consist of acicular **α' martensite and primary α-phase**: **left figure**.

The microstructure of Ti-6Al-4V alloy after the heat treatment, with air-cooling from **the α+β-field** (950 ^{o}C) is shown in the **right figure**. The structure contains a **lamellar mixture of α + β phases, primary α-phase** and grain boundary α. Considering the low cooling rate no α' martensite is formed.

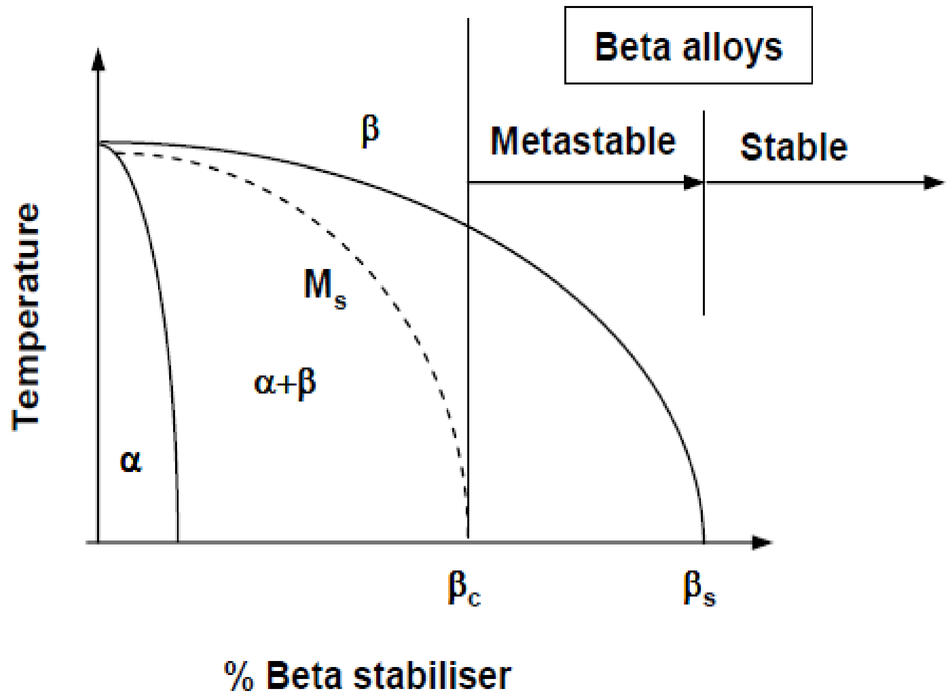




Ti-ALLOYS AND THEIR HEAT TREATMENT: Beta Ti-alloys

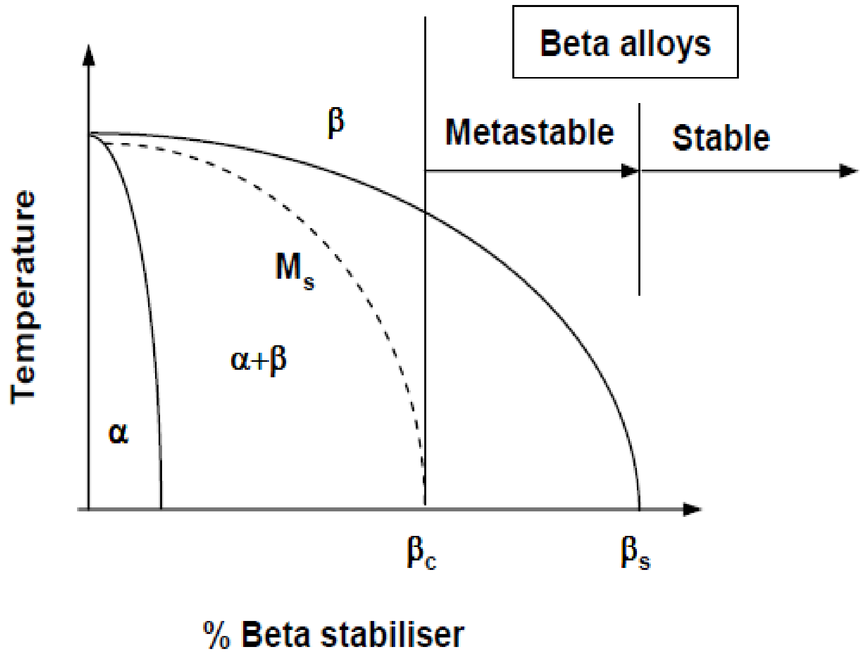
Beta stabilisers are sufficiently added to retain a **fully β-structure** (avoid martensite formation) when quenched from the β-phase field.

In the figure the conditions of the **metastable** and **stable formations of β-alloys** are shown.



Ti-ALLOYS AND THEIR HEAT TREATMENT: Beta Ti-alloys

Metastable and **stable formations of β-alloys,** and their limits:



β-Stabilizer	Type	$β_c$ (wt.%)[a]
Mo	Isomorphous	10.0
V		15.0
W		22.5
Nb		36.0
Ta		45.0
Fe	Eutectoid	3.5
Cr		6.5
Cu		13.0
Ni		9.0
Co		7.0
Mn		—

Ti-ALLOYS AND THEIR HEAT TREATMENT: Beta Ti-alloys

Metastable β-structures (in full volume) can be produced **by rapid cooling** while **stable β-structures** (in full volume) remain **after a simple air-cooling** (steady, equilibrium cooling, leaving alone the alloy) at room temperature.
The limits of these two types are given in the molybdenum equivalent, whose definition is:

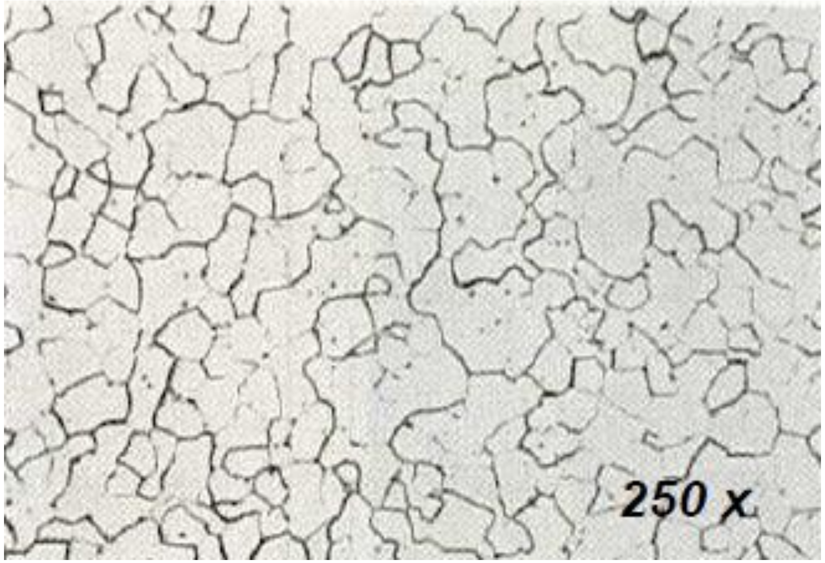
$$Mo_{equiv}\% = 1.0Mo + 0.67V + 0.44W - 0.28Nb + 0.22Ta + 1.6Cr + ... - 1.0Al$$

The **limits for the metastable and stable cases** are:

- Metastable β-alloys : Mo_{equiv} <25 (%),
- Stable β-alloys : Mo_{equiv}: 25-40 (%).

Ti-ALLOYS AND THEIR HEAT TREATMENT: Beta Ti-alloys

β-Ti alloys possess a BCC crystal structure, which is **readily cold-worked** (better than HCP α structure) in the β-phase field. The microstructure after quenching contains equiaxed β-phase, see the figure. After solution heat treating + quenching a very high strength (up to 1300-1400 MPa) can be reached.



Ti-13V-11Cr-3Al alloy solution heat-treated and water-quenched

Ti-ALLOYS AND THEIR HEAT TREATMENT: Beta Ti-alloys

Metastable β-Ti alloys are hardenable while **stable β-Ti alloys are non-hardenable**.

Most β-titanium alloys are metastable and **tend to transform** into:

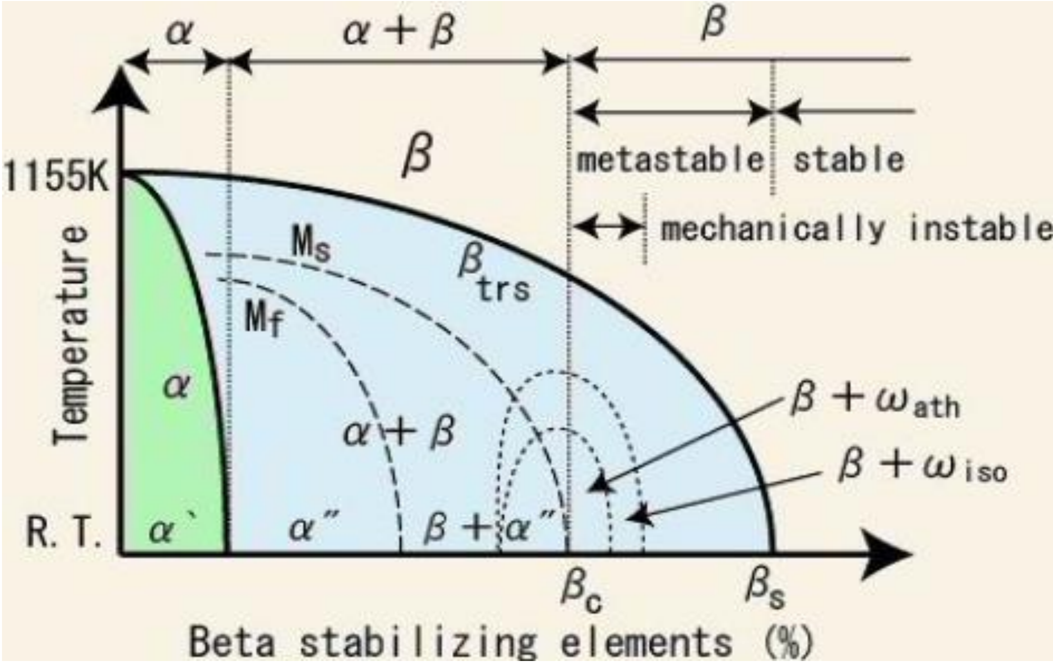
- coarse **α-plates** after heat-treated in the α+β phase field or
- **α-phase precipitation** after long-term ageing at elevated temperature.

This effect gives higher strength to the alloy but can cause embrittlement which is not desirable when ductility is required.

Ti-ALLOYS AND THEIR HEAT TREATMENT: Beta Ti-alloys

A **more detailed classification of the Ti-alloys containing β-stabiliser** alloying element(s) can be seen in the figure.

It has to be mentioned that the **production and heat treatment of the β-Ti alloys and α-β-Ti alloys need especially great care, because there are undesirable** (harmful) **phases** (e.g. the ω-phase) whose existence can destroy the good properties which were achieved by the previous, expensive technologies, therefore their formation has to be avoided.



Ti-ALLOYS AND THEIR HEAT TREATMENT: Beta Ti-alloys

In the following tables **different types, properties, applications, advantages and disadvantages of the β-Ti alloys** are summarised.

Advantages and disadvantages of beta titanium alloys

Advantages	*Disadvantages*
– high strength-to-density ratio	– high density
– low modulus	– low modulus
– high strength/high toughness	– poor low and high temperature properties
– high fatigue strength	– small processing window (some alloys)
– good deep hardenability	– high formulation cost
– low forging temperature	– segregation problems
– strip producible – low-cost TMP* (some alloys)	– high springback
– cold formable (some alloys)	– microstructural instabilities
– easy to heat treat	– poor corrosion resistance (some alloys)
– excellent corrosion resistance (some alloys)	– interstitial pick up
– excellent combustion resistance (some alloys)	

* TMP: thermomechanical processing

Ti-ALLOYS AND THEIR HEAT TREATMENT: Beta Ti-alloys

Alloy composition	Commercial name	Category (Mo equivalent)	T_β (°C)	Actual and potential applications	Year introduced (company)
Ti-35V-15Cr	Alloy C	Beta (47)		Burn resistant alloy	1990 (P&W)
Ti-40Mo		Beta (40)		Corrosion resistance	1952 (RemCru)
Ti-30Mo		Beta (30)		Corrosion resistance	1952 (RemCru)
Ti-6V-6Mo-5.7Fe-2.7Al	TIMETAL 125	Metastab (24)	704	High strength aircraft fasteners	1990 (TIMET)
Ti-13V-11Cr-3Al	B120 VCA	Metastab (23)	650	Airframe, landing gear, springs	1952 (RemCru)
Ti-1Al-8V-5Fe	1-8-5	Metastab (19)	825	Fasteners	1957 (RMI)
Ti-12Mo-6Zr-2Fe	TMZF	Metastab (18)	743	Orthopedic implants	1992 (Howmedica)
Ti-4.5Fe-6.8Mo-1.5Al	TIMETAL LCB	Metastab (18)	800	Low cost, high strength alloy	1990 (TIMET)
Ti-15V-3Cr-1Mo-.5Nb-3Al-3Sn-.5Zr	VT35	Metastab (16)		High strength airframe castings	n.a. (Russian)
Ti-3Al-8V-6Cr-4Mo-4Zr	Beta-C	Metastab (16)	795	Oil-fields, springs, fasteners	1969 (RMI)
Ti-15Mo	IMI 205	Metastab (15)	727	Corrosion resistance	1958 (IMI)
Ti-8V-8Mo-2Fe-3Al	8-8-2-3	Metastab (15)	775	High strength forgings	1969 (TIMET)
Ti-15Mo-2.6Nb-3Al-0.2Si	Beta 21S	Metastab (13)	807	Oxidation/corrosion resist, MMC	1989 (TIMET)
Ti-15V-3Cr-3Sn-3Al	15-3	Metastab (12)	760	Sheet, plate airframe castings	1978 (USAF)
Ti-11.5Mo-6Zr-4.5Sn	Beta III	Metastab (12)	745	High strength	1969 (Crucible)
Ti-10V-2Fe-3Al	10-2-3	Metastab (9.5)	800	High strength forgings	1971 (TIMET)
Ti-5V-5Mo-1Cr-1Fe-5Al	VT22	Metastab (8)	850	High strength forgings	n.a. (Russian)
Ti-5Al-2Sn-2Zr-4Mo-4Cr	Ti-17	Beta-rich (5.4)	885	High strength, medium temperature	1968 (GEAE)
Ti-4.5Al-3V-2Mo-2Fe	SP700	Beta-rich (5.3)	900	High strength, SPF	1989 (NKK)
Ti-5Al-2Sn-2Cr-4Mo-4Zr-1Fe	Beta CEZ	Beta-rich (5.1)	890	High strength, medium temperature	1990 (CEZUS)
Ti-13Nb-13Zr		Beta-rich (3.6)		Orthopedic implants	1992 (Smith&Neph)

REFERENCES, SOURCES:

[1] H.Bhadeshia: Metallurgy of Titanium and its Alloys, MSc egyetemi jegyzet, Cambridge University, 2003,
http://www.msm.cam.ac.uk/phase-trans/2003/titanium.movies/titanium.html

[2] Tapany Udomphol: Titanium and its alloys, MSc egyetemi jegyzet, Suranaree University of Technology Thailand, 2007,
http://eng.sut.ac.th/metal/images/stories/pdf/05_Titanium%20and%20titanium%20alloys.pdf

[3] Peter Pinke, Mihály Réger: Heat treatment of the casted Ti6Al4V titanium alloy
https://www.mtf.stuba.sk/buxus/docs/internetovy_casopis/2005/mimorc/pinke.pdf

Pinke Péter, Réger Mihály, Marcinka Roderik: Ti6Al4V jelölésű öntött titánötvözet hőkezelés utáni szövetszerkezetének vizsgálata, XI. Fiatal Műszakiak Tudományos Ülésszaka, Kolozsvár, 2006, 309-314. oldal