Leghe del TITANIO

Il titanio puro e' polimorfo esistendo in due strutture:
il titanio α a reticolo esagonale compatto stabile fino a 882 C
il titanio β, cubico a corpo centrato stabile fra 882 C e la T di fusione che e' di 1678 C.
Le proprieta' del titanio a temperatura ambiente sono molto interessanti

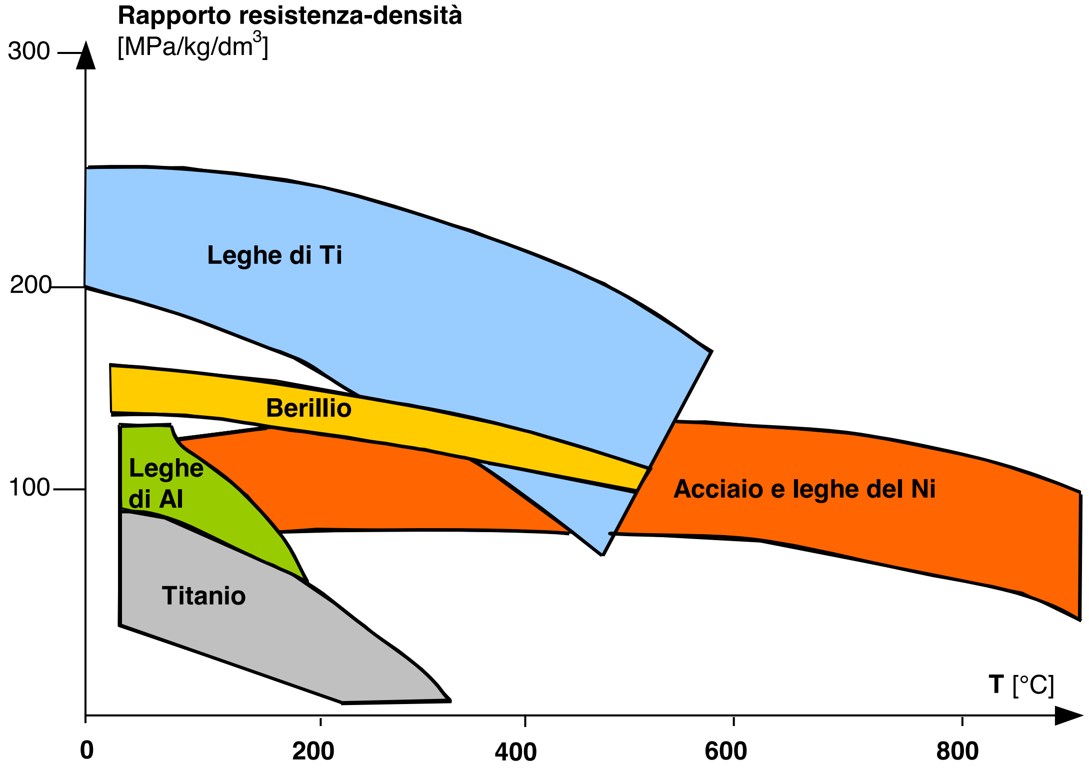
- densita' = 4,51 g/cm^3
- σ_y = 460 MPa e σ_T= 560 MPa ε= 22%, **HB = 200 - 220 (bassa!)**
- se viene laminato σ_T = 800 MPa e ε= 8%
- modulo di Young = 114 GPa
- non e' magnetico
- conducibilita' termica = 19 W/m C
- coefficiente di espans. termica = 8,4 x 10^{-6} C

Dal punto di vista della resistenza alla corrosione il titanio ha un ottimo comportamento in molti ambienti paragonabile a quello di un acciaio inossidabile 18/8. La resistenza del titanio all'acqua di mare e' paragonabile a quella del platino, la resistenza all'erosione e' anche altissima (acqua di mare ad alta velocita' e vapore in pressione), 20 volte superiore a quella delle leghe Cu-Ni.

All'incirca il 95% del titanio viene consumato in forma di ossido (TiO_2), nelle vernici, nella carta, nei cementi per renderli più brillanti e nelle plastiche. Le vernici fatte con il biossido di titanio riflettono molto bene la radiazione infrarossa e sono quindi molto usate dagli astronomi.

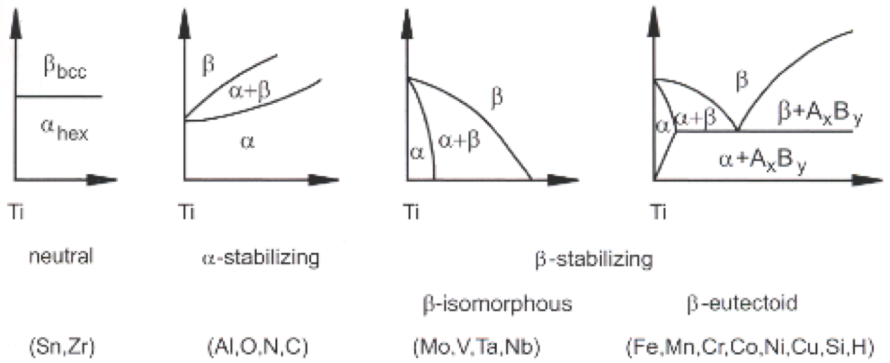
Il consumo mondiale di Titanio (2007) e' stato di circa 125.000 ton

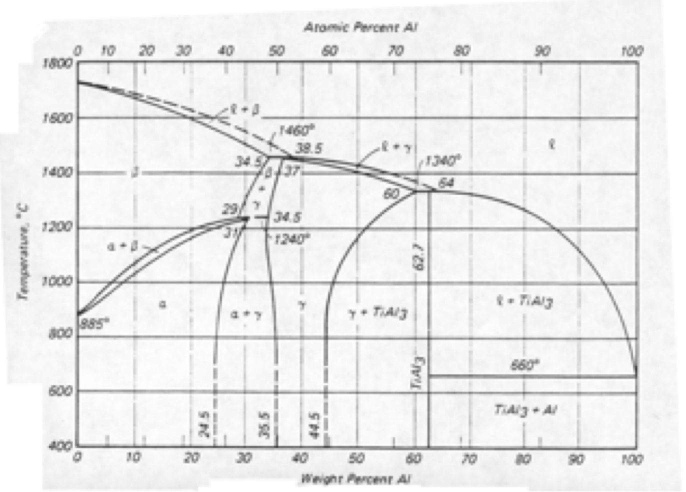
- aeronautico e difesa (48.000 ton)
- chimico, petrolchimico, energetico, edile (48.000 ton)
- beni di consumo (10.000 ton)
- biomedico



Leghe industriali del titanio

A temperatura ambiente il Ti ha struttura cristallina **esagonale chiamata alfa**; a circa 882°C, la fase alfa si trasforma in una struttura **cubica a corpo centrato, chiamata beta**, che è stabile fino al punto di fusione 1660 C





La principale influenza degli elementi aggiunti al titanio e' quella di allargare o di restringere i campi di esistenza della fase a.

1 = **Al**, O, N, C, Ga (α stabilizzanti)

2 = Mo, W, V, Ta (β stabilizzanti)

3 = (diagrammi con eutettico), Cu, Mn, Cr, Fe, Ni, Co, H

------ = inizio e fine trasformazione martensitica

Tra gli elementi stabilizzanti della fase α si ricordano principalmente **Al**, O, N

Questi elementi hanno inoltre la proprieta' di produrre un indurimento della fase solida a.

stabilizzanti della fase β sono invece altri elementi quali il **V**, Mn, Cr, Fe, **Nb**, **Mo**, Ta.

I due piu' importanti sono il V ed il Mo. Il Mo e’ poco usato, poiche' ha un' alta densita'

Leghe α

Le leghe alfa sono un pò meno resistenti a corrosione rispetto al titanio non legato, ma possiedono resistenza maggiore sia di quest'ultimo che di tutte le altre leghe di titanio; inoltre, resistono all'ossidazione ad alte temperature (300°C - 540°C) e presentano miglior saldabilità rispetto ai vari tipi di titanio CP ed ottima duttilità.
I livelli di resistenza a temperatura ambiente, comunque, sono i più bassi e queste composizioni non rispondono a trattamento termico.
La principale variabile microstrutturale delle leghe alfa è la dimensione del grano.

Vengono divise in tre gruppi:

- **solamente fase α**
- **fino a 2% di fase β (near α)**
- **invecchiabili (fino a 2.5% di Cu) - Ti_2Cu**

La lega piu' nota del primo gruppo e' la

Ti - 5Al - 2.5Sn (adesso anche ELI)

σ = 850 MPa. (puo’ operare anche a -200 C)

Una tipica lega **near *α*** e' la

Ti - 11Sn – 2.25Al - 5Zr - 1Mo - 0,2Si

Lo Sn e' migliore dell' Al (s.s.) ad alte temperature

Zr da anche s.s.

Mo stabilizza la fase β

Si si scioglie nella fase *α* e aumenta la resistenza meccanica e quella al creep

Sono state messe in commercio nuove composizioni con **0.2% di Pd** per migliorare la resistenza alla corrosione (1500 volte meglio) e altre composizioni chiamate **ELI** per migliorare la tenacita'.

Beta titanium alloys

Beta titanium alloys are the most versatile class of titanium alloys. **They offer the highest strength to weight ratios and very attractive combinations of strength, toughness, and fatigue resistance at large cross sections.** Some of the disadvantages compared to **α+β** alloys are increased density, a rather small processing window, and higher cost.

A beta alloy is a titanium alloy with sufficient **β**-stabilizer to suppress the martensitic transformation during quenching to room temperature.

The beta stability can be described by the molybdenum equivalent, which combines the effects of the various **β**-stabilizing elements like Mo, V, Fe, Cr, Nb, etc. A minimum value of about 10% is necessary to stabilize the beta phase during quenching

Tab. 2.2 Composition, category, applications, source and year of introduction of major beta titanium alloys [2].

Alloy composition	*Commercial name*	*Category*	*Mo-Eq u.*	*Actual and potential applications*	*Introduction Year-by*
Ti-35V-15Cr	Alloy C	beta	47	burn-resistant alloy	90-P & W
Ti-40Mo		beta	40	corrosion resistance	52-RemCru
Ti-30Mo		beta	30	corrosion resistance	52-RemCru
Ti-6V-6Mo-5.7Fe-2.7Al	TIMETAL 125	metastable	24	high-strength fasteners	90-TIMET
Ti-13V-11Cr-3Al	B 120 VCA	metastable	23	airframe, landing gear, springs	52-RemCu
Ti-1Al-8V-5Fe	1-8-5	metastable	19	fasteners	57-RMI
Ti-12Mo-6Zr-2Fe	TMZF	metastable	18	orthopedic implants	92-Howmedica
Ti-4.5Fe-6.8Mo-1.5Al	TIMETAL LCB	metastable	18	low cost, high strength alloy	90-TIMET
Ti-15V-3Cr-1Mo-0.5Nb-3Al-3Sn-0.5Zr	VT 35	metastable	16	high strength airframe castings	na*-Russia
Ti-3Al-8V-6Cr-4Mo-4Zr	Beta C	metastable	16	oil fields, springs, fasteners	69-RMI
Ti-15Mo	IMI 205	metastable	15	corrosion resistance	58-IMI
Ti-8V-8Mo-2Fe-3Al	8-8-2-3	metastable	15	high strength forgings	69-TIMET
Ti-15Mo-2.6Nb-3Al-0.2Si	TIMETAL 21S	metastable	13	oxidation/corrosion resistant, TMCs	89-TIMET
Ti-15V-3Cr-3Sn-3Al	15-3	metastable	12	sheet, plate, airframe castings	78-USAF
Ti-11.5Mo-6Zr-4.5Sn	Beta III	metastable	12	high strength	69-Crucible
Ti-10V-2Fe-3Al	10-2-3	metastable	9.5	high strength forgings	71-TIMET
Ti-5V-5Mo-1Cr-1Fe-5Al	VT 22	metastable	8.0	high strength forgings	na*-Russia
Ti-5Al-2Sn-2Zr-4Mo-4Cr	Ti-17	beta-rich	5.4	high strength, medium temperature	68-GEAE
Ti-4.5Al-3V-2Mo-2Fe	SP 700	beta-rich	5.3	high strength, SPF	89-NKK
Ti-5Al-2Sn-2Cr-4Mo-4Zr-1Fe	Beta-CEZ	beta-rich	5.1	high strength, medium temperature	90-CEZUs
Ti-13Nb-13Zr		beta-rich	3.6	orthopedic implants	92-Smith & N.

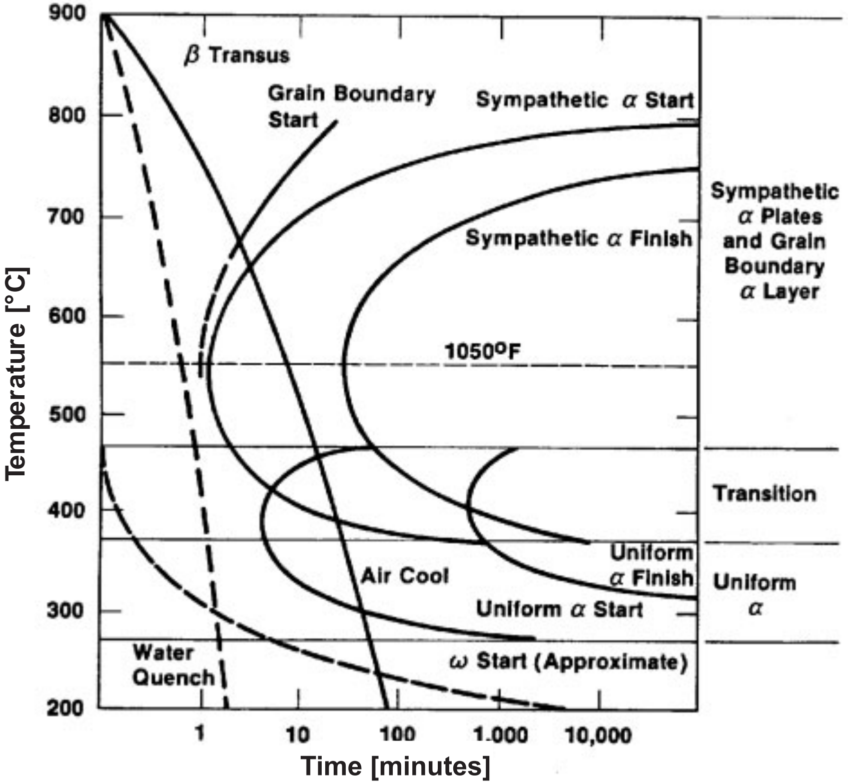


Fig. 2.2 Qualitative TTT-diagram for Ti-10-2-3 (β-ST) [4, 5].

Processing of β alloys usually consists of a hot working operation followed by a heat treatment. The final hot working step is normally performed in the α+β field for the leaner β alloys, and preferentially in the β field for the richer beta alloys. The heat treatment consists of a solution treatment followed by quenching and a subsequent aging treatment.

A solution heat treatment above the β -transus temperature results in coarse β grains

Solution treating slightly below the β transus leads to the precipitation of primary α (α_p). The heat treatment temperature controls the α_p volume fraction, while forging and rolling deformation influences the α_p shape. Without working a needle-like ap shape develops; an increased amount of hot working leads to a globular ap shape.

At lower temperatures, typically 400 to 600 C, the secondary α (α_s) precipitates in a fine distribution. **It has a significant strengthening effect depending on its volume fraction and size, which in turn are controlled by aging temperature and time as well as by the solution treatment temperature.** The precipitation of α_s can be homogeneous as it is found in lean beta alloys like Ti-10-2-3, or inhomogeneous in richer beta alloys, like Beta C or Ti-15-3. Cold work generally enhances the aging response and can lead to a more homogenous distribution of the α_s.

Tensile Properties

Through aging, a wide range of yield stresses (typically 900 to 1400 MPa) can be reached in β titanium. With increased aging, however, all β alloys show a significant reduction in ductility. In more highly β -stabilized alloys like Ti-15-3 or Beta C, with an inhomogeneous as precipitation, duplex aging procedures have been developed. They consist of "high/low"- or "low/high" aging sequences. Duplex aging allows, for example, higher strength in shorter time than single-step aging. Duplex aging was mainly developed for an improvement of toughness and fatigue resistance.

Besides the dominating effect of aging, primary α_p can also influence ductility.

A coarsening of the α_p as well as a change from globular to acicular leads to a reduction in ductility in Ti-10-2-3.

Fracture Toughness

Increased aging significantly reduces fracture toughness.

Fractography has revealed that as for ductility, an increased strain localization and increased strength difference between the soft α_p and the aged matrix is the reason for this trend.

Duplex aging has been tried in order to increase the strength and toughness compared to single-step aging. ***Results are mixed for different alloys…..***

For Ti 15-3 K_{IC} from 43 to 66 MPa √m (with high/low aging) but for Ti 10-1-3 is better low/high…..

Fatigue

The good fatigue potential of beta alloys is well known. A high cycle fatigue strength (HCF) around 700 MPa can be achieved in Ti-10-2-3 for large cross sections (> 100 mm); this is not possible for any other titanium alloy.

An increase in aging, or 0.2% yield strength, can increase HCF strength.

Richer beta alloys like Beta C or Ti-15-3 have a lower fatigue strength level than the leaner alloys such as Ti-10-2-3 or SP 700. One possible reason may be the trend for an inhomogeneous precipitation of as in the richer alloys. For Beta C crack nucleation occurs in the transgranular precipitate-free regions. Using a duplex aging procedure a more homogeneous as precipitation resulting in a 50 MPa increase in fatigue strength was achieved

A grain size reduction has been shown to increase the fatigue strength

Applications

Despite the obvious potential of beta alloys, their share of the titanium market is still small (1% of the US market). However, their use is continuously increasing, especially in aerospace. This is through increased use of existing alloys like Ti-10-2-3. Most of the landing gear of the Boeing 777 airplane, for example, is produced from Ti-10-2-3

In addition, the rotor head of the Westland Super Lynx helicopter is also produced from Ti-10-2-3 instead of Ti-6-4.

The driving force for selection of Ti-10-2-3 is increased fatigue properties of the beta alloy.

Outside aerospace, beta alloys can be used for downhole service (deep oil and gas wells) where Beta C is a particularly appropriate candidate because of its good combination of mechanical and corrosion properties.

New alloys under development are: TIMETAL LCB (LCB – low cost beta) with its first application in automotive springs, SP 700 as a high strength alloy with improved cold and superplastic formabilit, and TMZF (Ti-12Mo-6Zr-2Fe) as a surgical implant alloy with low modulus, good strength, and corrosion resistance.