"Titanium alloys: structure, properties and industrial application"

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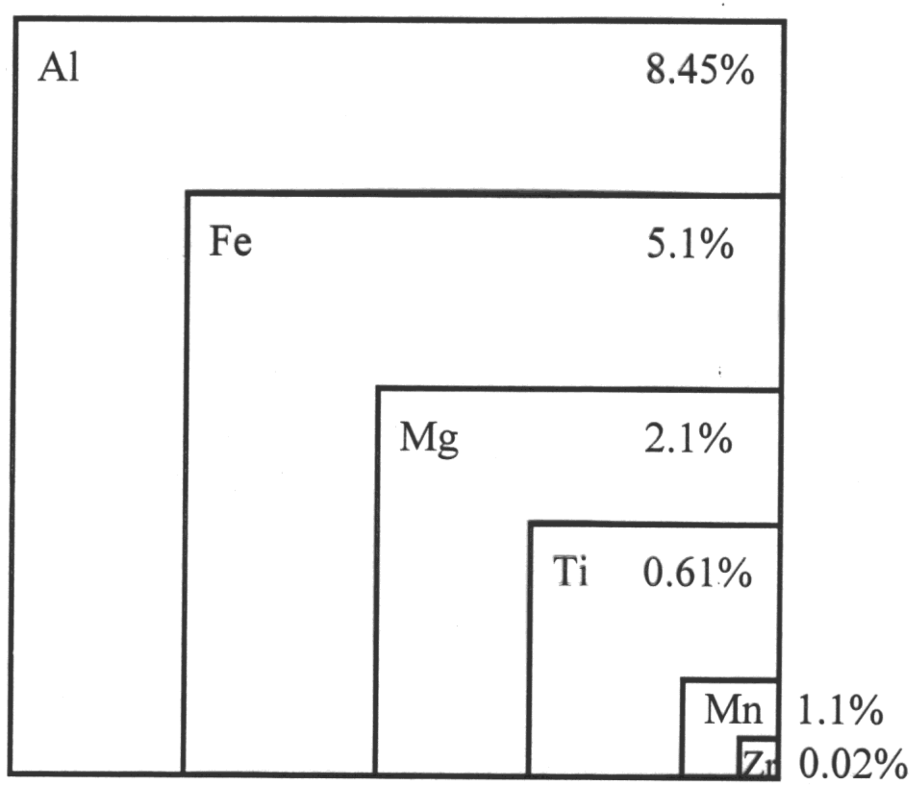
Contents of metals in terrestrial cortex



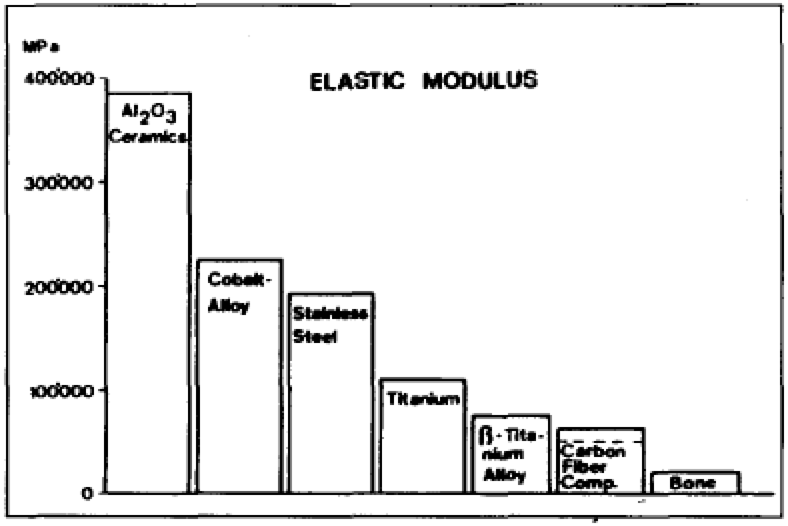


Fig. 2: Comparison of the elastic moduli of different implant materials.

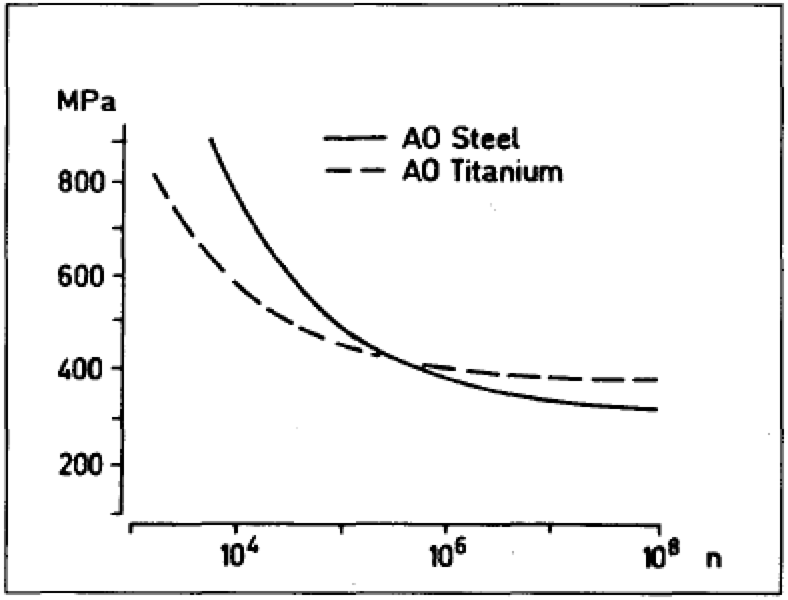
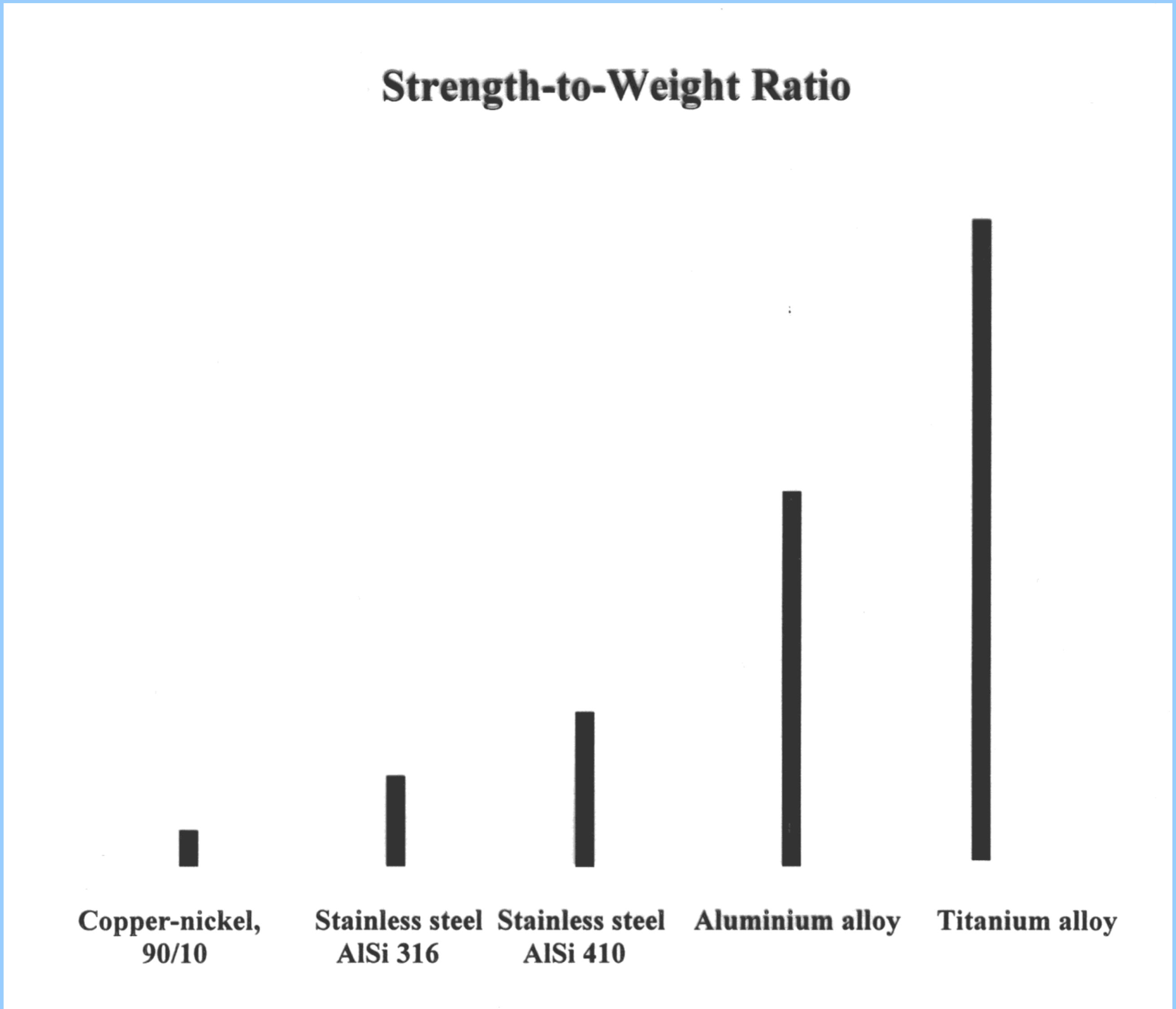


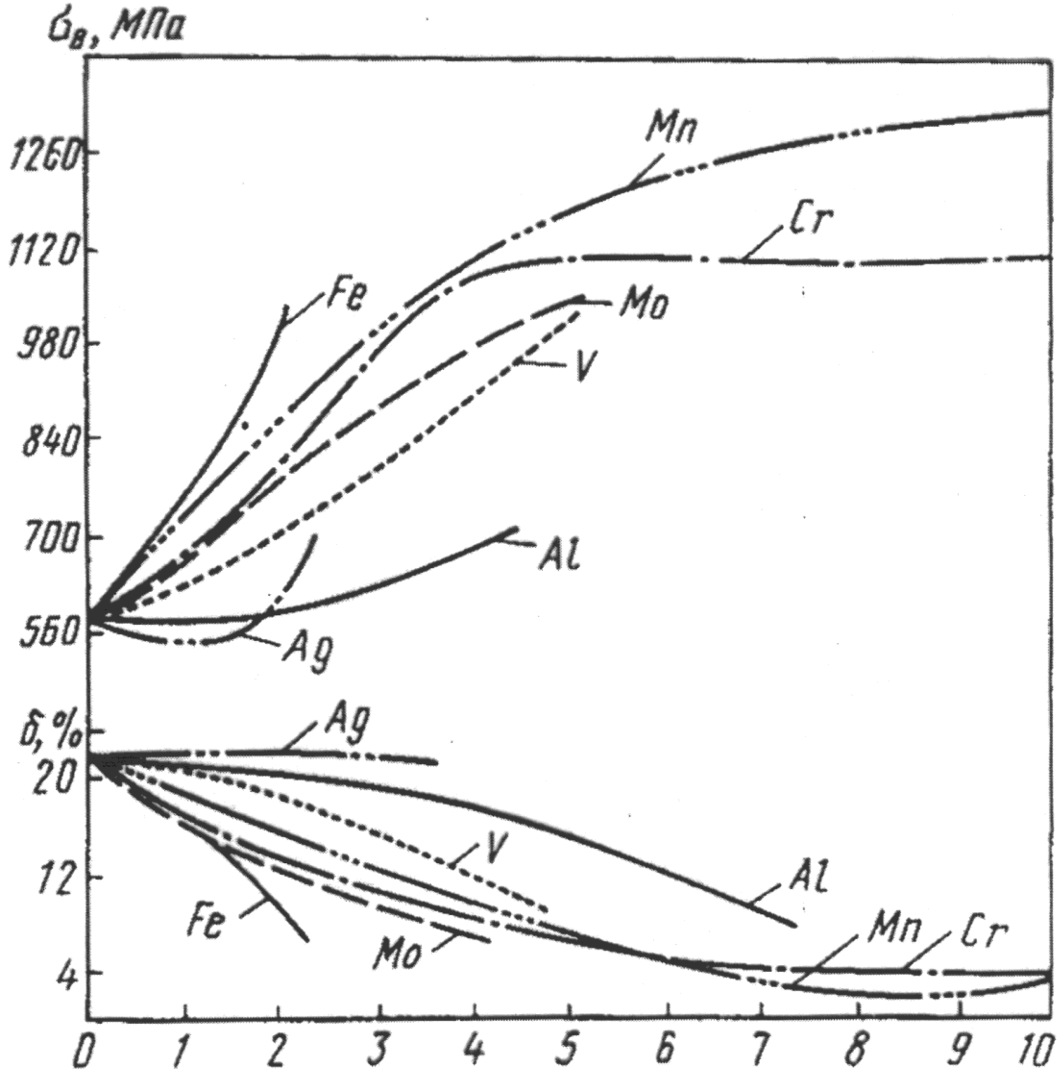
Fig. 3: Diagram showing applied stress versus number of cycles to failure with Wöhler curves of fully reversed bending fatigue-tests for implant c.p. titanium and stainless steel.


Strength-to-Weight Ratio
Copper-nickel, 90/10
Stainless steel AlSi 316
Stainless steel AlSi 410
Aluminium alloy
Titanium alloy

Periodic Table of the Elements

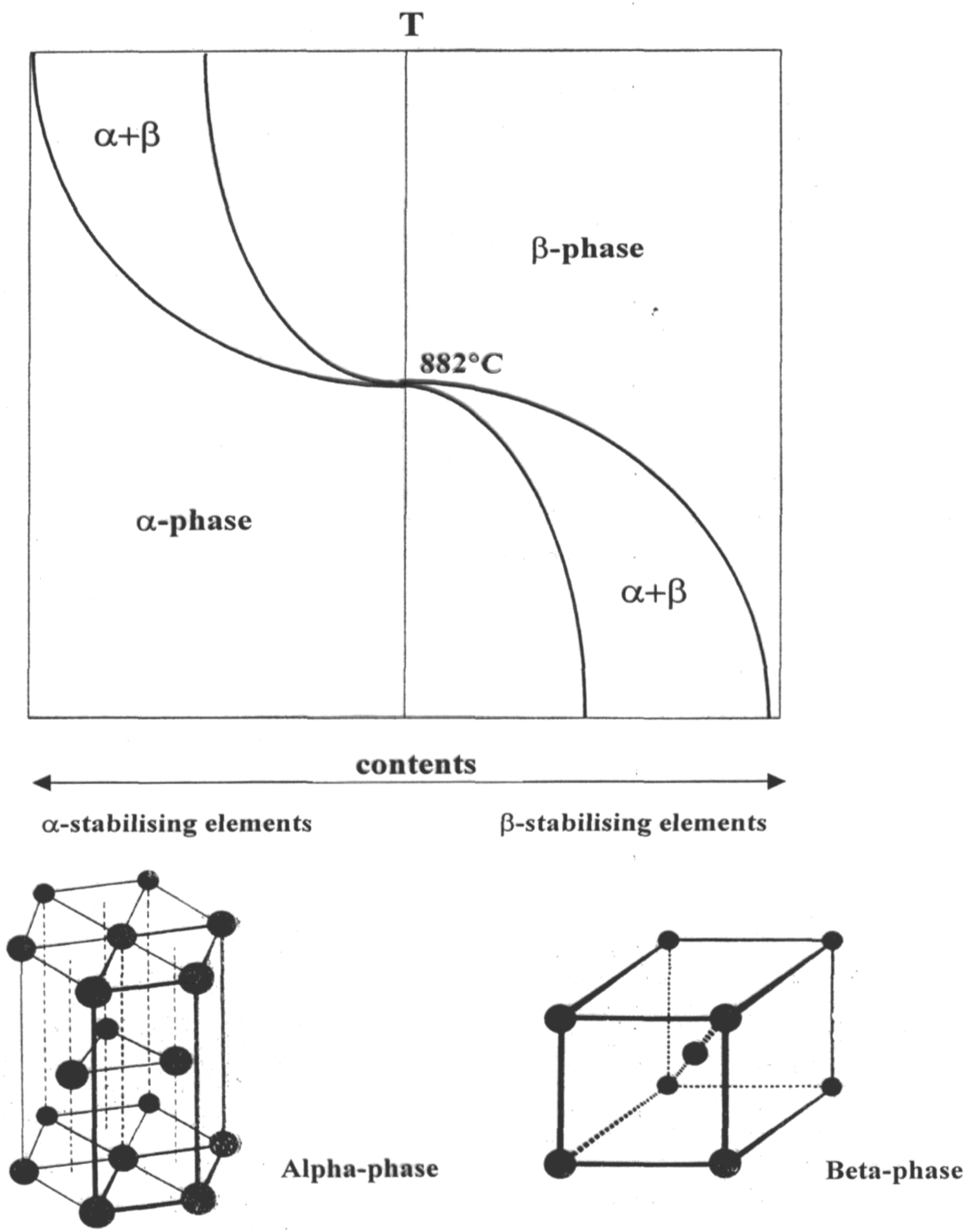
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

Effect of alloying metals on strength of titanium

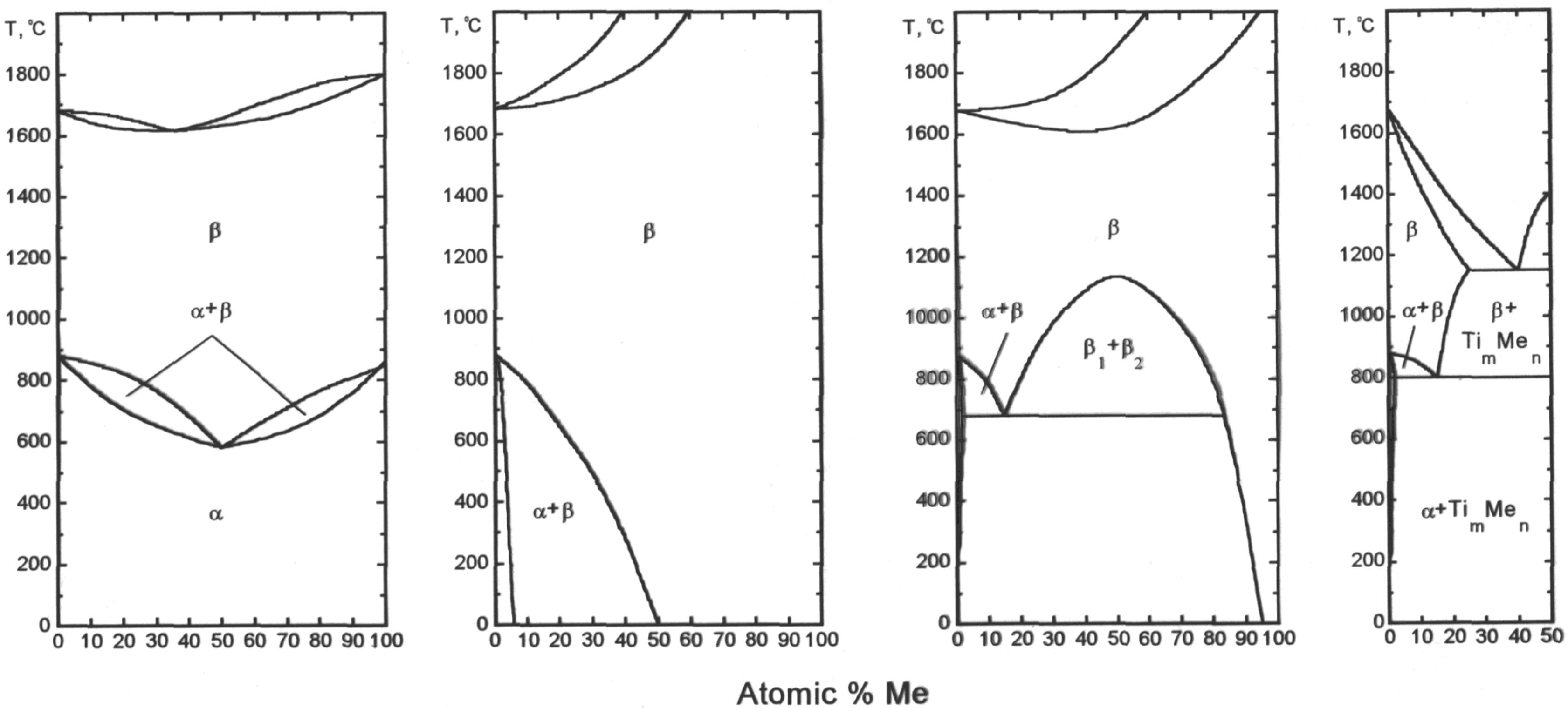


alloying metal, %

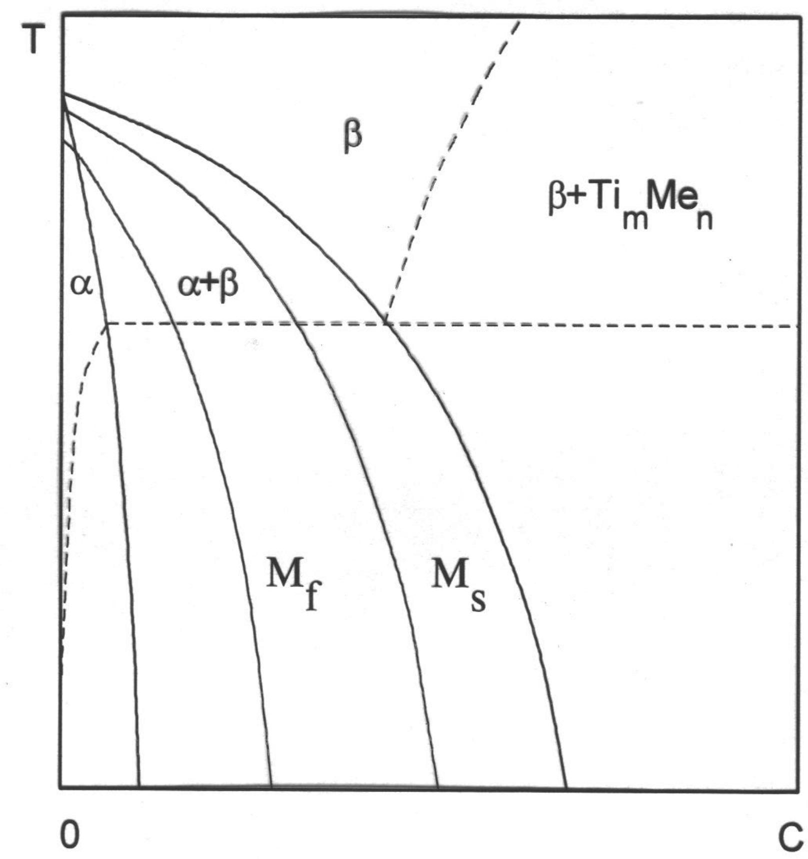
Influence of Alloying additions on the polymprphic transformation of titanium



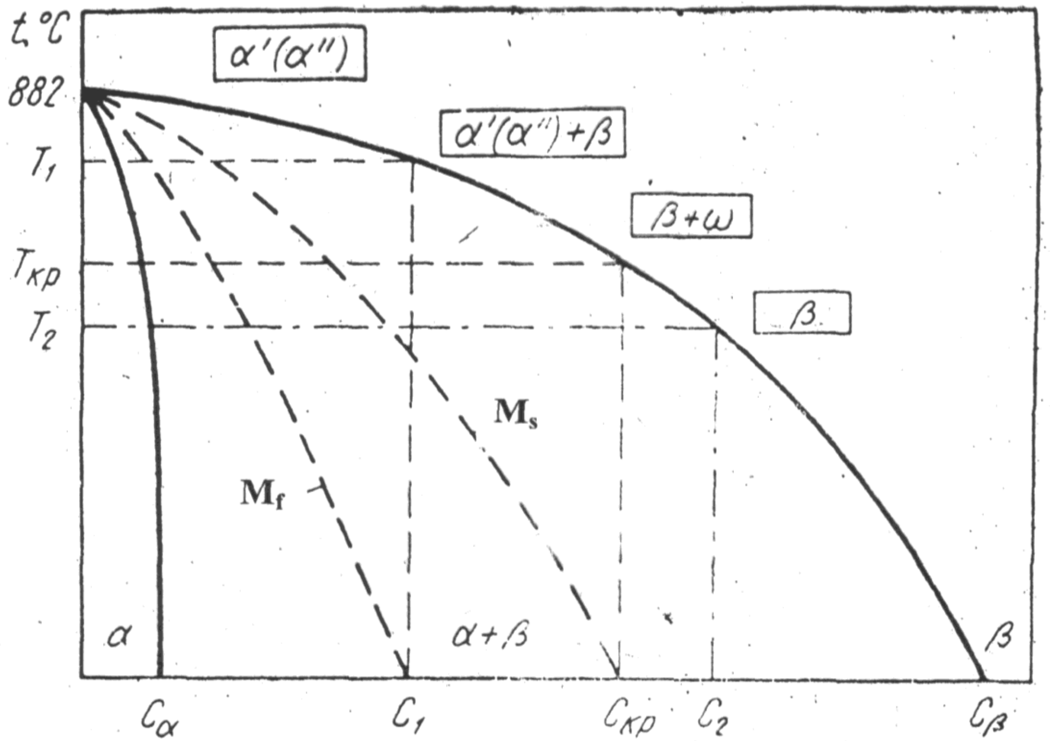
The main types of the phase diagrams of the binary titanium systems

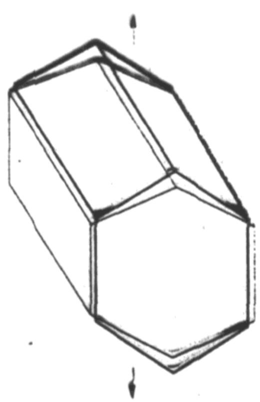


METASTABLE PHASE DIAGRAM FOR BINARY TITANIUM ALLOYS

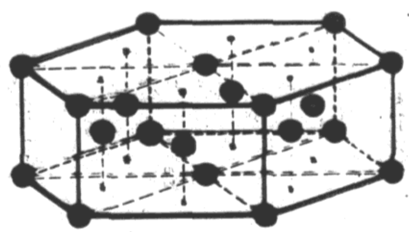


Types of phases forming after quenching from the β phase

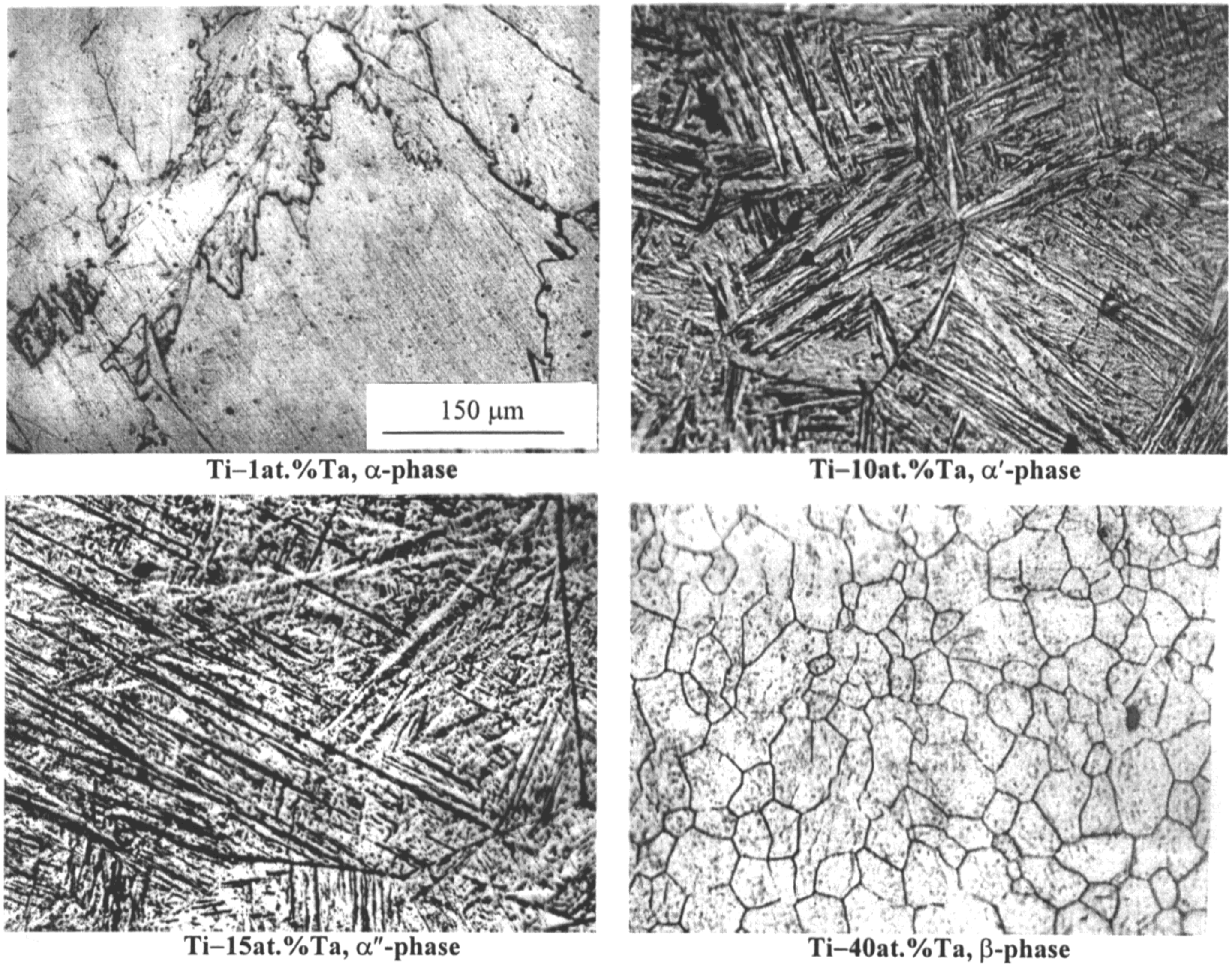




α''-phase



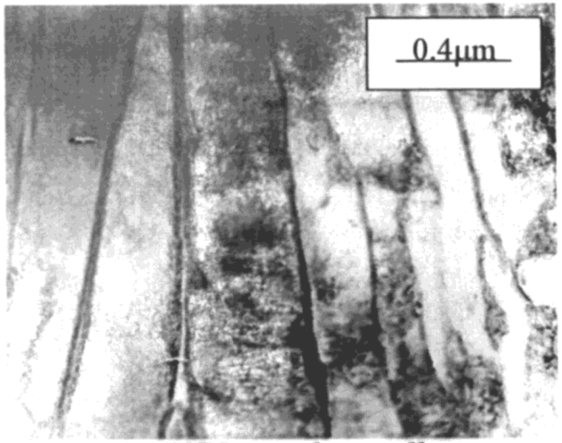
ω-phase



Microstructure of Ti-Ta alloys after quenching from the β phase

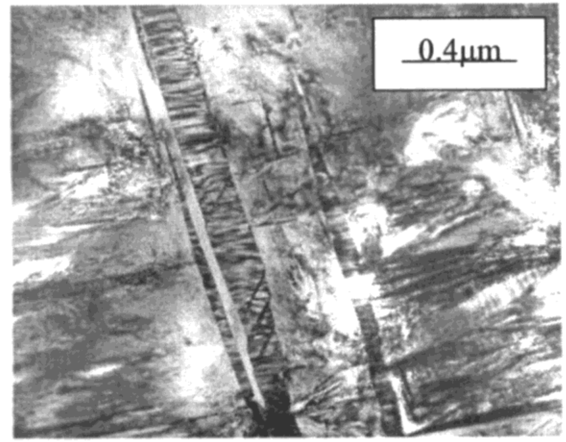
Microstructure of industrial titanium alloys after quenching from beta-phase

quenching 1000°C



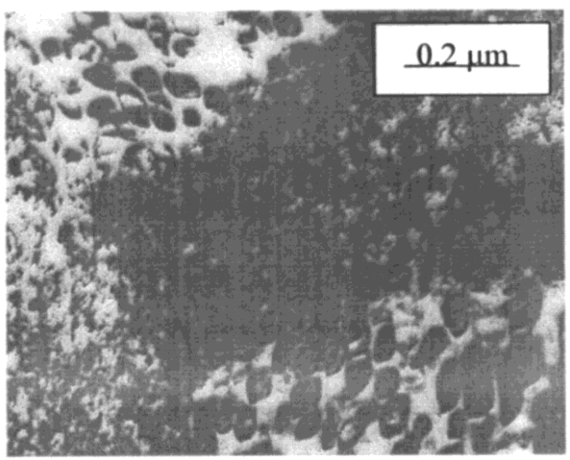
VT5, psevdo α - alloy

quenching 1100°C



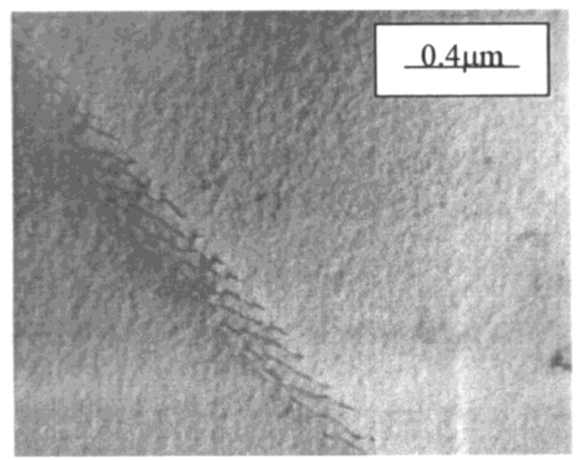
VT9, α+β alloy

quenching 1000°C+460°C, 1 h

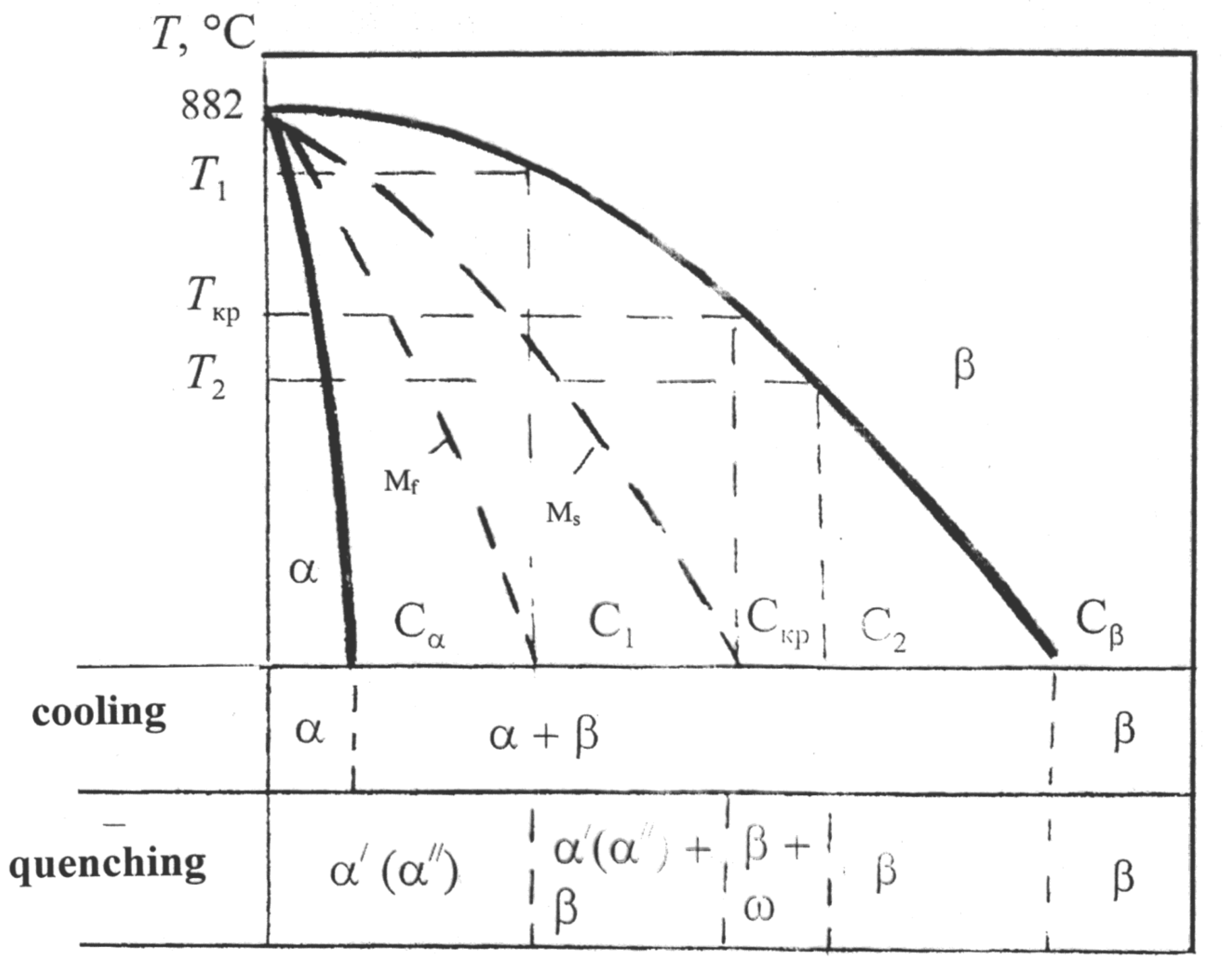


Ti–14 mas.%V, psevdo β-alloy

quenching 1000°C



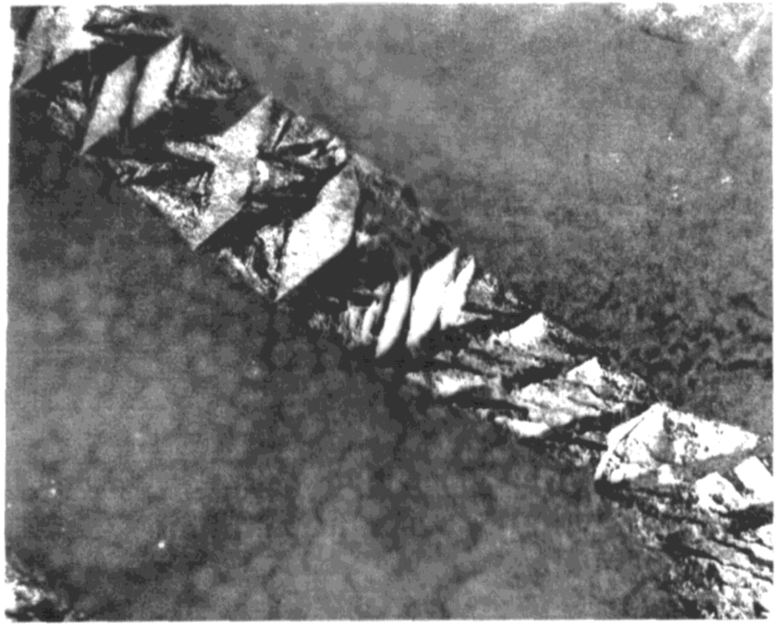
Ti-6 mas.%Cr, β-alloy



α-alloys non heat treatable, well weldable, medium strength and good toughness, high temperature creep strength and oxidation resistence (contain about 5-6%Al, Sn, Zr and Si for silicite precipitation

α+β alloys heat treatable, most weldable, good hot forming ability including superplastic forming, creep resistence not as good as α alloys TypicalTi6Al4V Contain also Mo and Sn

β-alloys heat treatable, most of them weldable, high strength up to intermediate temperature level, excellent cold formability. Contain Mo, Ta, Nb and V used as matrix for fiber composites



VT9, 950°C, 15′, x 40000

Microstructures of VT9 titanium alloy after quenching from the $\alpha + \beta$ region

To the left microstructure of VT9 alloy annealed 20’ at 750ºC and quenched 40000x

THE TITANIUM GLOBAL MARKET

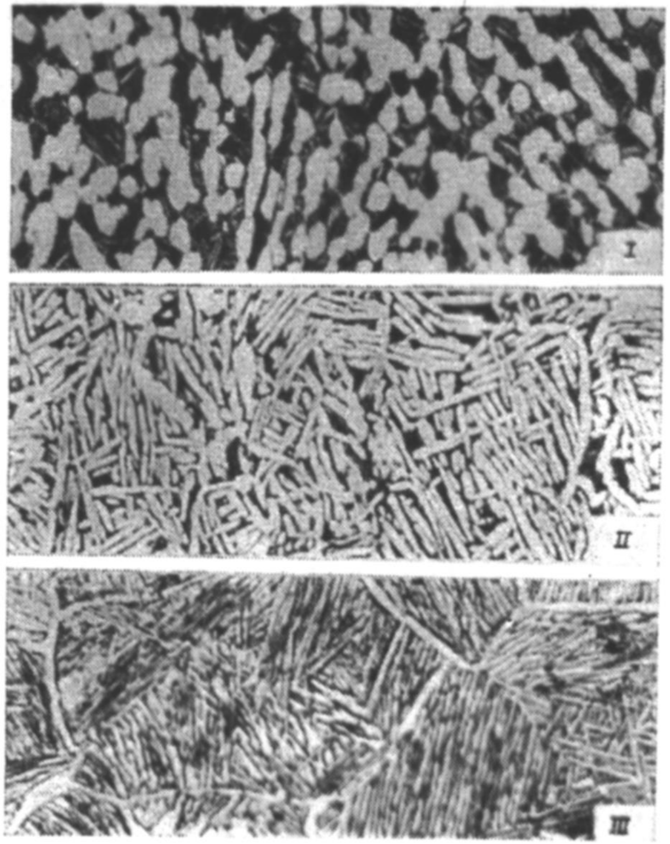
Metal	Global market (1000 metric tons)	$/ton
Steel	730.000	400
Aluminium	20.000	1.500
Stainless steel	13.000	2.000
Titanium	50	18.000 à 25.000

TITANIUM MARKET SEGMENTS	CONSUMPTION
CIVIL AEROSPACE	14000-19000 t
MILITARY AEROSPACE	3000-4000 t
ENERGY/CHEMICAL INDUSTRIES	20000-25000 t
SPORT & LEISURE	3000 t
ARCHITECTURE	500 t
MEDICAL	800 t
OTHER (including spectacle frames)	1000 t
TOTAL	**42300-53300 t**

Nomenclature of industrial titanium alloys

Alloy type	Russia alloys		American alloys	
	Common name	Composition	Common name	Composition
alpha alloy	VT1-00 VT1-0 VT5 VT5-1 4200	Unalloyed Ti Unalloyed Ti 5Al 5Al-2,5Sn 0,2Pd	Grade 1 Grade 2	Commercially pure Ti Commercially pure Ti 5Al-2,5Sn 5Al-5Zr-5Sn 8Al-1Mo-1V
near α-alloy	VT4 VT20	5Al-1,5Mn 6Al-2Zr-1Mo-1V		Ti-8Al-1Mo-1V Ti-6Al-2Nb-1Ta-0.8Mo
α+β - alloy	VT6C VT6 VT3-1 VT9 VT14 VT16 VT22 VT23	5Al-4V 6Al-4,5V 6Al-2,5Mo-2Cr-0,3Si-0,5Fe 6Al-3,5Mo-2Zr-0,3Fe-0,3Si 4,5Al-3Mo-1V 2,5Al-5Mo-5V 5Al-5Mo-5V-1Fe-1Cr 4,5Al-2Mo-4,5V-0,6Fe-1Cr		3Al-2,5V 6Al-2Sn-2Zr-2Mo-2Cr 6Al-4V 6Al-2Sn-4Zr-2Mo 6Al-2Sn-4Zr-6Mo 6Al-6V-2Sn 6Al-7Nb 7Al-4Mo 8Mn
near β-alloy	VT15 TC6	3Al-7Mo-11Cr 3Al-5Mo-6V-11Cr		3Al-8V-6Cr-4Mo-4Zr 10V-2Fe-3Al 11,5Mo-6Zr-4,5Sn 13V-11Cr-3Al
β - alloy	4201	33,0Mo		Ti-3Al-13V-11Cr Ti-3Al-10V-2Fe

Main types of structure of titanium alloys after different conditions of deformation



I – deformation in $\alpha+\beta$ region (on 30-50°C below β-transus);
II– beginning of deformation in β-region, completion of deformation in $\alpha+\beta$ region;
III-deformation in β-region

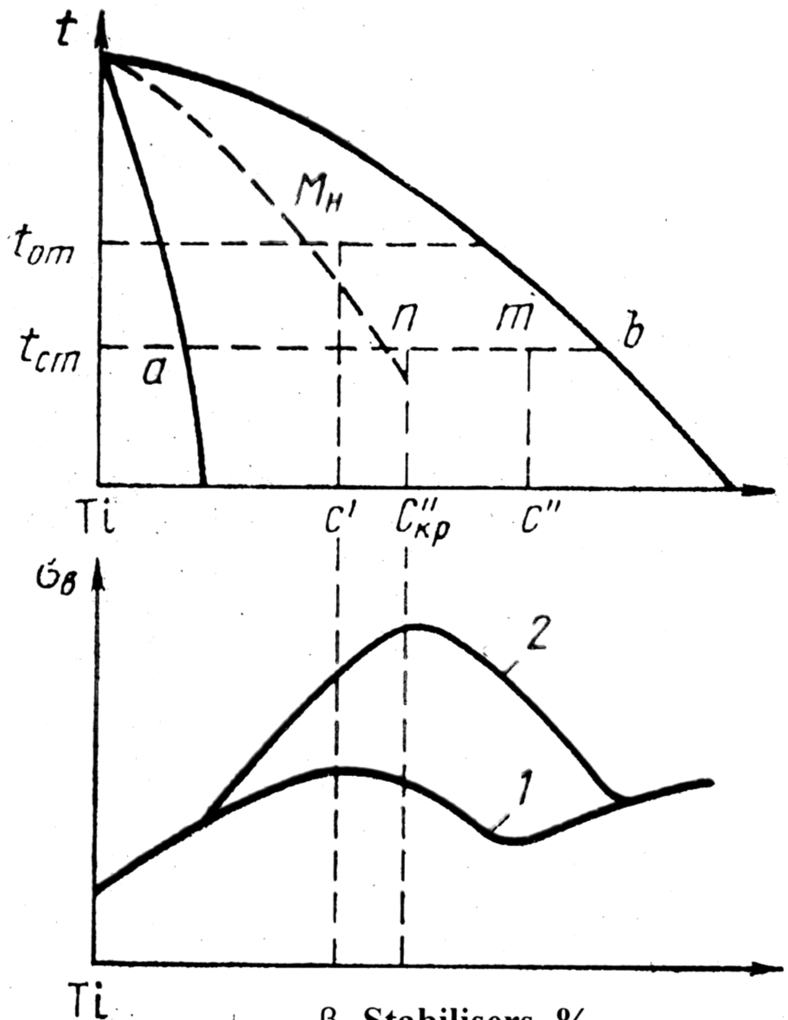
Classification by Strength

The preceding classification of titanium alloys according to metallographic structures has been included because a knowledge of the terminology is useful. A classification system more relevant to the designer, however, is one based on tensile. The classification system is given in table, which does not provide a complete list of titanium alloys but includes the more common ones in use in each of the strength ranges.

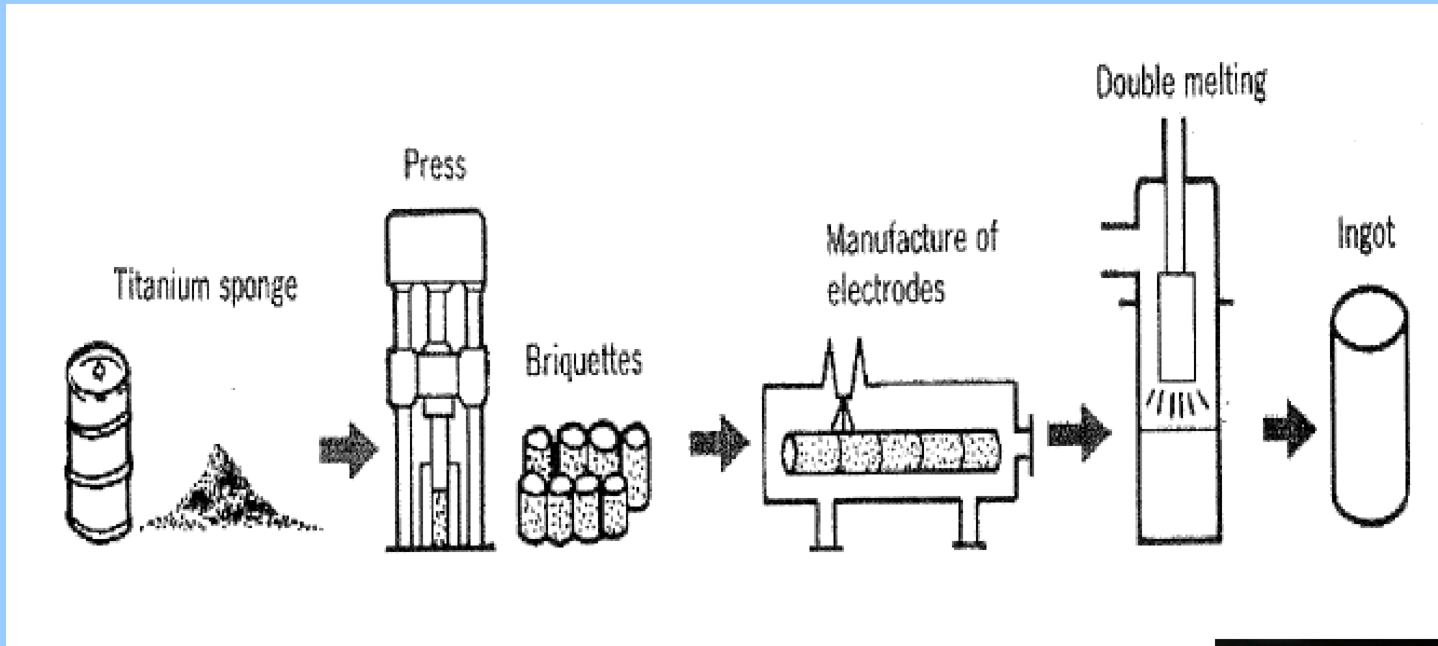
Table. Classification of titanium alloys by strength.

Category	Min Strength (MPa)	Composition
Low Strength	500	ASTM grades 1,2,3,7 and 11
Moderate Strength	500-900	ASTM grades 4,5, and 9 Ti-2.5%Cu Ti-8%Al-1%Mo-0.1%V
Medium Strength	900-1000	Ti-6%Al-2%Sn-4%Zr-2%Mo Ti-5.5%Al-3.5%Sn-3%Zr-1%Nb-0.3%Mo-0.3%Si
High Strength	1000-1200	Ti-3%Al-8%V-6%Cr-4%Zr-4%Mo Ti-4%Al-4%Mo-2%Sn-0.5%Si Ti-6%Al-6%V-2.5%Sn Ti-5%Al-2%Sn-4%Mo-2%Zr-4%Cr Ti-6%Al-5%Zr-0.5%Mo-0.2%Si Ti-6%Al-2%Sn-4%Zr-6%Mo Ti-5.8%Al-4%Sn-3.5%Zr-0.7%Nb-0.5%Mo-0.3%Si
Very High Strength	1200	Ti-10%V-2%Fe-3%Al Ti-4%Al-4%Mo-4%Sn-0.5%Si

Effect of ageing on strengths of titanium-base alloys



β- Stabilisers, %

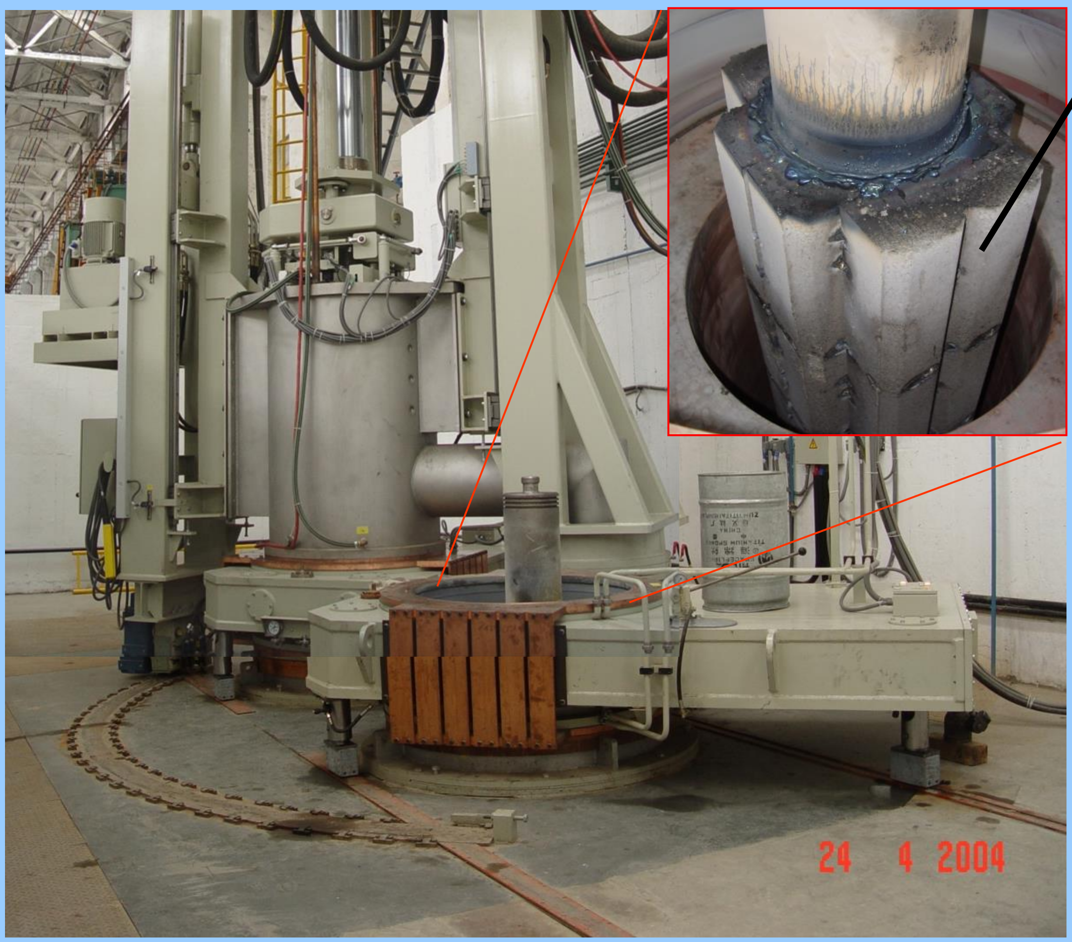


Vacuum Arc Remelting Furnace

<u>Ingot dimensions:</u>

Ingot diameter:	**1.275 mm**
Ingot length:	**3.760 mm**
Ingot weight:	**30.716 kg**
Material Grades:	**Ti and Alloys**

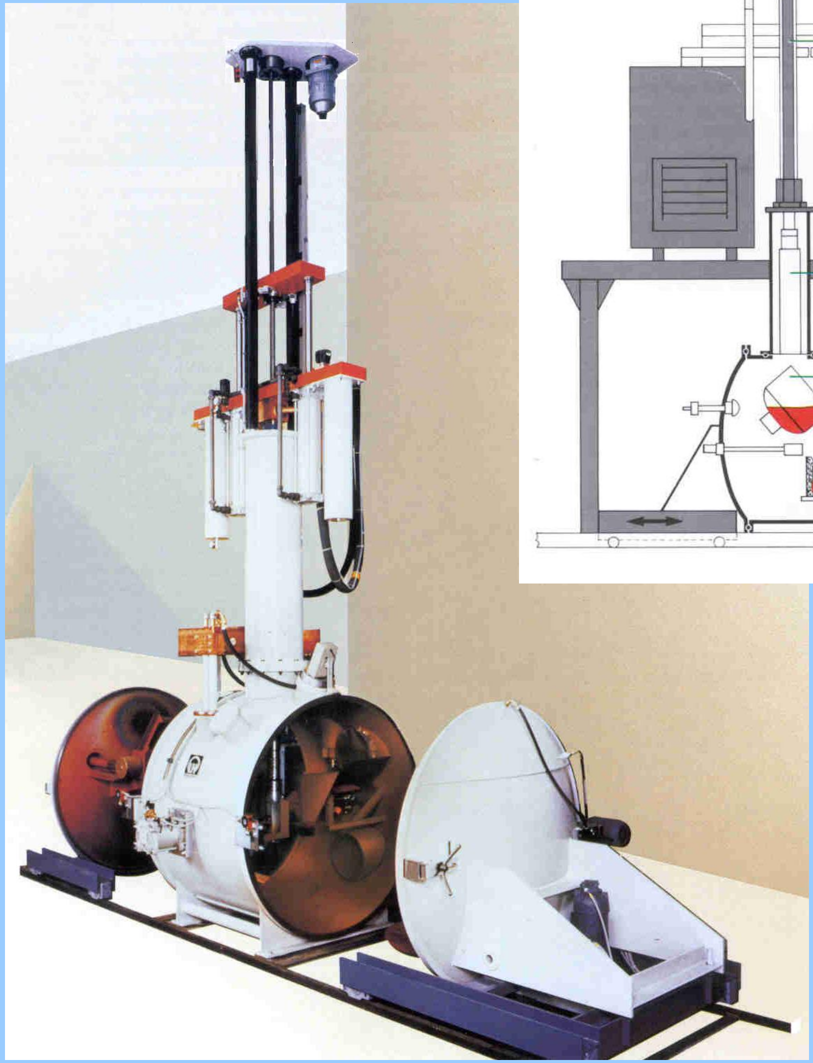
VAR Furnace with lock valve

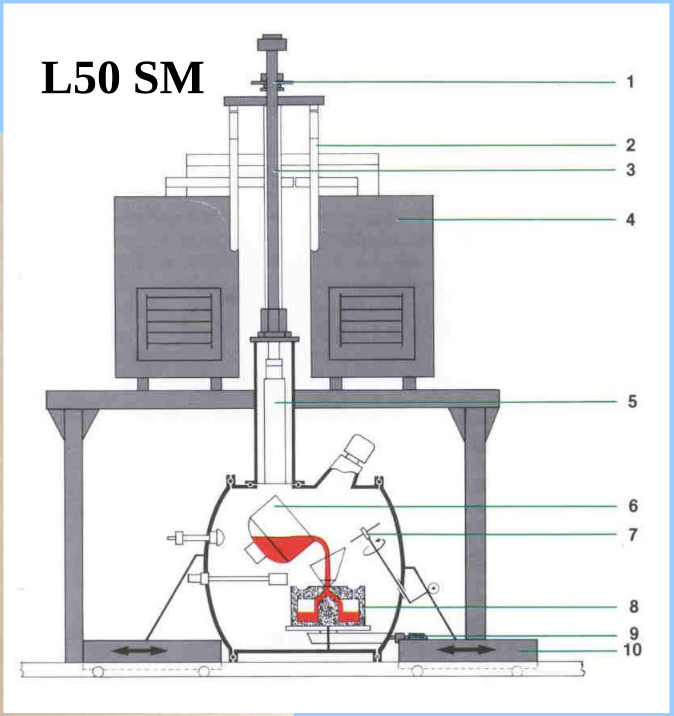


Sponge Electrode

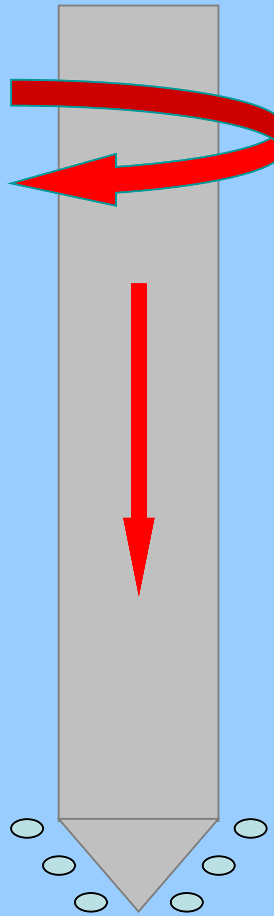
VAR Skull Melter

1 **Fast retraction system**
2 **Power cables**
3 **Electrode Feeder Ram**
4 **Power supplies**
5 **Consumable Electrode**
6 **Skull Crucible**
7 **Tundish Shield**
8 **Mold arrangement**
9 **Centrifugal Casting System**
10 **Chamber Lid Carriage**



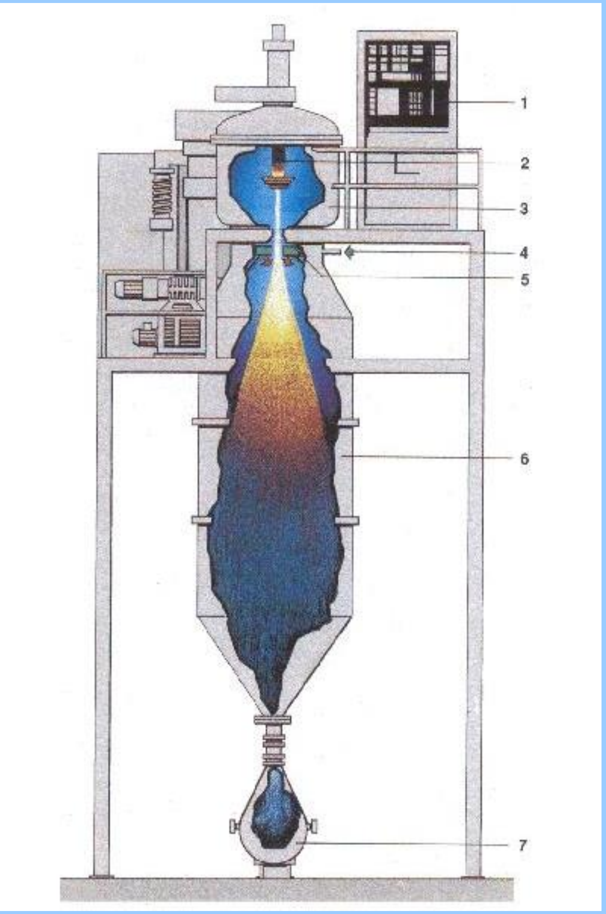


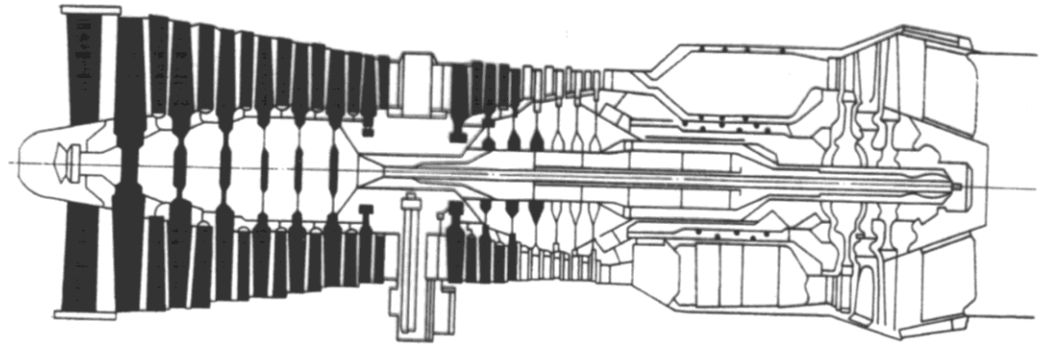
Electrode Inert-Gas Atomization Plant



Prozessparameter:

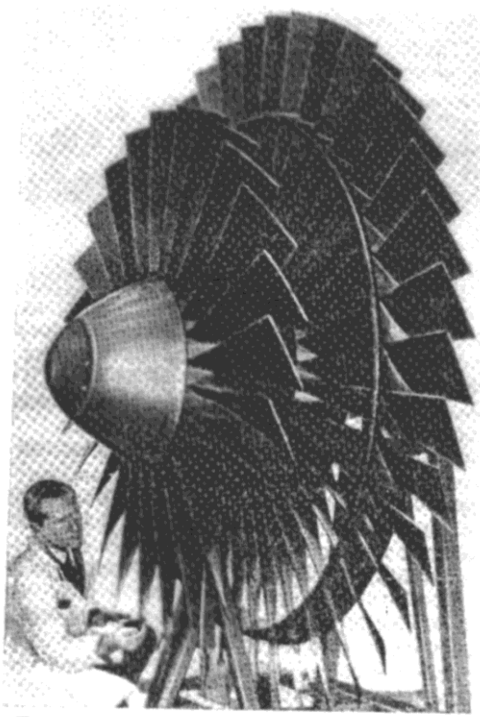
- Frequenz
- Strom / Spannung / Leistung
- Rotationsgeschwindigkeit
- Absenkgeschwindigkeit
- Elektrodenabstand zur Spule





Titanium parts

Engine for "Concord"



Rotor of ventilator for engine TF-39

Fig. 1. Front view of the all titanium SR-71 Blackbird.

Table 1
Candidate advanced titanium alloys for high speed aircraft structures

Alloy type	Alloy	Density ($g\,cm^{-3}$)	Chemistry	Rationale
α/β	Ti-6-4	4.43	Ti–6Al–4V	Industry standard-baseline
	Ti-6242S	4.54	Ti–6Al–2Sn–4Zr –2Mo–0.08Si	Creep strength, tough, high temperature
	Timetal 550	4.60	Ti–4Al–4Mo –2Sn–0.5Sn	Good SPF, toughness
	Ti-62S	4.43	Ti–6Al–1.7Fe –0.1Si	High Modulus, sheet, plate-forgings
	Ti-62222	4.54	Ti–6Al–2Sn–2Zr –2Cr–2Mo–(Si)	Good SPF, strength, toughness
	Corona X	4.42	Ti–5.0Al–5.5Mo –2Cr–1Ni–0.1O_2	Good strength, toughness
	Beta-CEZ	4.68	Ti–5Al–2Sn –4Mo–2Zr–2Cr –1Fe	High strength, toughness-forgings
	SP700	4.54	Ti–4.5Al–2Fe –2Mo–3V	Low temperature SPF, very tough
	Ti-10-2-3	4.65	Ti–10V–2Fe –3Al	High strength, toughness-forgings
Metastable β	Timetal 21 S	4.93	Ti–15Mo–2.7Nb –3Al–0.2Si	Heat treatable to a wide range of properties, readily produced in strip, cold rollable, potentially low cost
	LCB	4.79	Ti–4.5Fe–6.8Mo –1.6Al	
	Beta-C	4.82	Ti–3Al–8V–6Cr –4Mo–4Zr	