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Titanium and its Alloy

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Abstract: Iron is acknowledged as the most useful minerals ever mined from Earth, due to the various exclusive properties it has. Its physical and mechanical properties are proven desirable, is very manageable but it also has its issues like the fact that it is heavyweight, its corrosion resistance is low and its limitation in some fields, simultaneously propelling other companies and researchers to be in the lookout for other alternatives. Many have come to know of the advantages of titanium alloys in engineering applications. They are very strong and have great corrosion resistance, and can perform well at temperatures up to approximately 600°C with a density of about 60% of engineering steels and almost half that of nickel alloys. Despite its cost and supply issues, and how it is seen as an 'exotic' metal, the use of titanium in aerospace and military projects is on the increase. The specific properties of titanium and its alloys indicate that the cost-effective component manufacturing requires special techniques.

Keywords: Earth Element; Titanium and Titanium Alloys.

List of Symbol

Al	Aluminum
Bi	Bismuth
С	Carbon
Cr	Chromium
Cu	Copper
Fe	Iron
Ga	Gallium
Ge	Germanium
Н	Hydrogen
Hf	Hafnium
Li	Lithium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Ν	Nitrogen
Nb	Niobium
Ni	Nickel
0	Oxygen
Pb	Lead
Sb	Antimony
Sn	Tin
Si	Silicon
Та	Tantalum
Ti	Titanium
V	Vanadium
W	Tungsten

List of Abbreviations

- ASME American Society of Mechanical Engineers
- ASTM American Society for Testing Materials Extra-low interstitial impurities are made specific. These interstitial impurities are carbon,
- ELI hydrogen, oxygen and nitrogen and both the filler metal and base metal have low degree of impurities

1. Introduction

The high strength, low weight ratio and outstanding corrosion resistance which are natural in titanium and its alloys have brought about a wide range of successful applications requiring high levels of reliable performance in surgery and medicine as well as in aerospace, automotive, chemical plants and other major industries. In many of the engineering applications, titanium takes over heavier, less serviceable or less cost-effective materials. Designs created with the properties provided by titanium often produce dependable, economic and more durable systems and components. These titanium components often substantially surpass the performance and service life expectations at a lower overall cost. Titanium can be obtained in several different grades. Pure titanium is not as formidable as the different titanium alloys. Titanium (Ti-6Al-4V) alloy is one that is most extensively used. It has a credible machinability and excellent mechanical properties. For various weight reduction applications in aerospace, automotive and marine equipment, the alloy has the best overall performance. Ti-6Al-4V is also known to have various applications in medicin. The biocompatibility of Ti-6Al-4V is exceptional, especially when the requirement is to have a direct contact with tissue or bone (Figure 1).



Figure 1: Density of selected metals [3]

2. Engineering Materials

To be able to define titanium, one must know the engineering materials' family up to the point when the titanium site is visited. Engineering materials refer to all materials used in the construction sites or industries or both. The following figure can be referred to, in order to learn more about the engineering materials (Figure 2):



Figure 2: Engineering Materials

Based on figure 1, titanium is definable as one of the nonferrous metals, normally used in the industries and construction sites. Given its advantages titanium it is evidently desirable in several military, civilian, and medical uses, (Figure 2).



Figure 3: Mendeleev periodic table [1]

Totalling 0.6%, titanium sits at the fourth rank among iron, aluminium, and magnesium, and ninth among all elements in the earth's crust. However, to date it is still considered an exotic and costly material. The majority of titanium serves as oxide (about 95%) as whitener or filler material in the paint industry. Not many people realize that titanium, as oxide is abundant in everyday life, e.g. in toothpaste, white paint, sun block. The main reason why it has taken a long time to use titanium as a metal is due to the difficult and costly reduction of oxide to metal [3].

3. Short story

In 1791 Reverend William Gregor (1761-1817), a novice mineralogist, found a strange-looking, black, sandy substance in his neighbourhood. As it appeared magnetic, he made a calculation that it was nearly 50% magnetite (a form of iron ore). What remained of the sample was a reddishbrown powder he dissolved in acid to produce a yellow substance. Ouite confident that he had discovered a new mineral, he named it "menachanite," after the Menachan region in Cornwall where he lived. In the same period, Franz Joseph Muller (1740-1825) also discovered something similar that he could not recognize. In 1793 Martin Heinrich Klaproth (1743-1817), who had found several new elements and is deemed the father of modern analytical chemistry, identified the substance that Gregor thought was a new element. Klaproth called it "titanium," meaning "Earth" in Latin. The name also refers to the Greek mythology titans (Figure 4) [1, 2, and 3].



Figure 4: Titans, the powerful sons of the earth in Greek mythology [4]

4. The Metallurgy of Titanium (Crystal Structure)

Similar to other metals, titanium can crystallize in various crystal structures at a wide range of temperatures. Transformation that is complete from one into another crystal structure is called allotropic transformation, while the respective transformation temperature is "transition temperature".

Pure titanium and most of the titanium alloys, crystallize at low temperatures in an ideally modified hexagonal close packed structure (HCP), called α titanium. At high temperatures, however, the body-centered cubic structure (BCC) is characteristically stable and is referred to as β titanium. The β transition temperature for pure titanium is noted as $882\pm 2^{\circ}$ [3]. The atomic unit cells of the hexagonal close packed (HCP) α titanium and the body-centered cubic (BCC) β titanium are schematically illustrated in Figure 5 with the highlights being their most densely packed planes and directions. Both crystal structures, which are different, and the corresponding allotropic transformation temperatures are vital since they constitute the basis for the multiple properties achieved by titanium alloys. Both plastic deformation and diffusion rate are very much attached with the respective crystal structure. Furthermore, the hexagonal crystal lattice causes a distinctive anisotropy of mechanical behaviour for α -titanium, and the elastic anisotropy is particularly pronounced. The Young's modulus of titanium single crystals varies consistently between 145 GPa for a load vertical to the basal plane and only 100 GPa parallel to this plane [3].



Figure 5: Crystal structure HCP for α , and BCC for β phase [3]

5. Effects of Alloying Elements [6]

An extensive range of mechanical and physical properties can be obtained through a selective addition of alloying elements to titanium. The fundamental effects of a number of alloying elements are stated below:

- 1. Certain alloying additions, two of which are aluminium and interstitials (O, N, and C), have the tendency to stabilize the alpha phase, i.e., increase the temperature where the alloy will be transformed completely to the beta phase. This temperature is acknowledged as the beta transition temperature and illustrated in (Figure 6).
- 2. Most alloying additions stabilize the beta phase by reducing the transformation temperature (from alpha to beta).
- 3. Some elements notably tin and zirconium adopt behaviour like the neutral solutes in titanium and have little impact on the transformation temperature, where they serves as strengtheners of the alpha phase.

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Titanium alloy microstructures characteristically have a number of alloy additions and processing. A description of the various kinds of alloys and typical photomicrographs of various mill products manufactured are illustrated (Figure 7).



Figure 6: Specific strength versus use temperature of selected structural materials compared with titanium alloys and aluminides [3]



6. The Classification of Titanium Alloys

The classifications of titanium and its alloys follow the amount of α and β kept in their structures at room temperature, and they include commercially pure, α and near α , $\alpha - \beta$, and metastable β . In essence, the commercially pure and α alloy have all- α microstructures. β alloys primarily have all- β microstructures after the air-cooling process from the solution treating temperature above the β transus. $\alpha - \beta$ alloys carry a mixture of α and β phases at room

temperature. The general classification of the alloying elements can be seen in Figure 8 [5, 6, and 7].



Figure 8: Three-dimensional phase diagram to classify Titanium alloys [3]

6.1 α-stabilizers

Pure titanium at room temperature contains α hexagonal close-packed crystal "HCP" structure. The a-stabilizers have both substitutional and interstitial alloying elements. The substitutional α stabilizers are Al, Ga, Ge, and interstitial α stabilizers are O, N, and C. Among the substitutional alloying elements, Al is the most extensively used since it has large solubility in both α and β phases and it lessens the alloy's density. In Ti-alloys, Al addition is limited up to 5-6 wt% since the Ti-3Al (α 2) phase will be formed with the increasing Al content. The two-phase region α + Ti-3Al starts about 5 wt% Al. The formation of Ti-3Al (α 2) coherent phase makes the Ti alloys brittle. The equivalent Al content in the multi-component Ti-alloys is shown in Figure 9(a). A schematic phase diagram with α stabilizing element is shown in Figure 9. Other substitutional alloying elements are Ga, Ge and rare earth elements despite the fact that their solubilities are much lower than Al and O.O. N and C all are strong α -stabilizers. These alloying elements tend to be stronger but it also lowers the ductility of Ti alloys. At room temperature, commercially pure titanium is primarily composed of a-phase. As alloying elements are added to titanium, they tend to alter the amount of each phase that is present and the β transition temperature [5, 6, and 7].



Figure 9: shows different types of phase diagrams of Ti,(a) is a schematic phase diagram for alpha stabilizing alloying additions, (b) is a schematic phase diagram for beta isomorphous alloying additions, (c) is a schematic phase diagram for eutectoid formers, (d) is a schematic phase diagram for neutral alloying element [5]

6.2 B-stabilizers

The alpha (α) transforms to a (β) BCC structure at an estimated temperature of 885 °C Figures 8 and 9. This transformation temperature, alternatively known as the β transition temperature, can be raised or lowered governed by the type and amount of impurities or the alloying additions. Broadly speaking, β -stabilizers are transition metals and they are divided into two categories, namely β-isomorphous and β -eutectoid. β -isomorphous stabilizers have thorough solid solubility with β Ti. β isomorphous elements adopted in titanium alloys are V, Nb, and Mo. It is possible for sufficient concentrations of these elements to stabilize the β phase to room temperature as shown in Figure 9(b). Ta and W are seldom used due to their density considerations. The β-eutectoid stabilizers commonly used for alloying with Ti are Cr, Fe, and Si while W, Cu, Ni, Mn are Bi are known to have highly restricted usage. A schematic phase diagram is shown in Figure 9(c). Hydrogen is also a β eutectoidforming element and has a low eutectoid temperature of 300°C. The high diffusivity of hydrogen causes it to adopt a special process of microstructure refinement, which uses hydrogen as an impermanent alloying element. Cr is restricted up to 5 wt% because otherwise, it will form the intermetallic compound Ti-Cr2 which is undesirable. Similarly, Fe is limited to 5.5 wt%. Si is a common addition to titanium alloys for high temperature applications and it can improve creep resistance [5, 6, and 7].

6.3 Neutral elements

Sn, Zr and Hf are considered neutral elements because they tend to reduce the α/β transformation temperature only slightly and then they increase the transformation temperature again at even higher concentrations. Zr and Hf both show the same β to α allotropic phase transformation, and are isomorphous with both phases of titanium as shown in Figure 9(d) [5,6, and 7]. The type and amount of these alloying elements ascertain the common phases, which are present at low temperatures. Based on these phases, titanium alloys are classified into four main classes which are α , near- α , $\alpha + \beta$ and β alloys. Figure 10 is a schematic of a pseudobinary phase diagram of titanium alloys which contain α and β stabilizers [5, 6, and 7].



Figure 10: A pseudobinary titanium phase diagram [5]

6.4 a- Alloys

The α stabilizers are elements that increase the β transition temperature by bringing stability to the α phase and they include Al, O, N, and C. Aluminium, the principal α stabilizer, is known to enhance the tensile strength, creep strength, and elastic moduli Figure 9(a). [5, 6, and 7].

6.5 Near- α Alloys

α alloys, which contain small amounts (about 1 to 2 wt%) of β stabilizers, stabilizing 5-10% of the β phase into the structure at room temperature have been classified as near-α alloys. The presence of the β phase enables two-phase strengthening via a control over the two phases' scale, morphology and distributions. Near-α alloys are largely used in the high operational temperature in the compressor section and they have the best resistance for creep of all Ti-alloys at temperatures above 400 °C [5, 6, and 7].

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14	Density	Heat	Heat Treatment Thickness d [mm]	YS [MPa]	S UTS Pa] [MPa]	%El	%RA	KIc [MPa√m]	
Alloy	[g cm- 3]	Treatment						min	typical
Ti %99.5	4.5	annealed	≤ 80	200	290-420	24	-	-	-
Ti 99.4	4.5	annealed	≤ 80	290	390-540	20	30	-	-
Ti 99.2	4.5	annealed	≤ 80	490	540-740	15	25	-	-
T: 20	150	annealed	≤ 80	400	540	16	35	-	-
11-2Cu	4.30	aged	≤ 80	540	650	10	30	-	-
Ti-5Al-2.5Sn (Grade 6)	4.46	annealed	≤ 100	760	790	10	25	-	70
Ti-6Al-2Sn-4Zr-2Mo-0.1Si	4.55	aged	≤ 80	830	900	8	20	50	60
Ti-5.8Al - 4Sn-3.5Zr-0.7Nb - 0.5Mo - 0.35Si	4.55	aged	≤75	880	1000	6	15	I	45
T: 5 41 2 5Ec	1 15	annealed	≤ 50	780	860	8	25	-	-
11-5AI-2.5Fe	4.43	annealed	$50 \le d \le 160$	780	860	8	20	-	-
	4.43	annealed	≤ 80	830	900	10	25	50	70
Ti-6Al-4V		annealed	$80 \le d \le 150$	830	900	8	20	-	70
(Grade 5)		aged	≤13	1030	1100	8	15	-	45
		aged	$13 \le d \le 25$	1000	1070	8	15	-	-
TI 6A1 AV ELL	1 13	annealed	≤ 75	795	860	10	25	-	95
11-0AI-4V ELI	4.45	annealed	$75 \le d \le 100$	760	830	10	20	-	95
Ti 441 4Mo 2Sp	4.60	aged	≤ 100	920	1050	9	20	-	60
11-4A1-410-2511	4.00	aged	$100 \le d \le 150$	870	1000	9	20	-	60
Ti 641 6V 28n	4.54	annealed	≤ 80	930	1000	8	20	-	45
11-041-0 -2311	4.34	aged	≤ 25	1100	1200	6	15	-	35
Ti-6Al-2Sn-4Zr-6Mo	4.65	aged	≤150	940	1080	4	-	55(β)	75(β)
		Aged highest strength	≤ 75	1105	1195	4	-	44	55
Ti-10V-2Fe-3Al	4.65	aged high strength	≤ 100	1035	1100	6	-	60	75
		Aged medium strength	≤100	895	965	8	20	88	100

6.6 $\alpha + \beta$ alloys

 $\alpha + \beta$ alloys contain more β phase than the near- α alloys. These alloys can be fortified by heat treatment (Table1.) and thermo-mechanical processing Figure 11. They have better combinations of strength, and ductility than do the near α alloys. $\alpha+\beta$ alloys applications include structural components of military and commercial aircraft, fan and compressor blades in gas turbine engines, to name but a few [5,6,7].

T.L. 1.



amount of α and β [5]

6.7 β alloys

 β stabilizers are elements that lower the β transition temperature. As shown in Figure 9.(c, d) and Figure 10, they are classified into two groups: β isomorphous and β eutectoid. The isomorphous alpha phase is obtained from the

metastable beta decomposition in the first group, and an intimate eutectoid mixture of α and a compound form in the second group. The isomorphous group consists of elements which are completely miscible in the β phase; molybdenum, vanadium, tantalum, and niobium can be found in this group. The eutectoid-forming group, that has eutectoid temperatures as high as 335°C below the transformation temperature of unalloyed titanium, includes manganese, iron, chromium, cobalt, nickel, copper, and silicon. However, the eutectoid reactions can be very sluggish in some of the said alloys, thus in real-time, these alloys tend to act as if the reaction is non-existent (Figure 12) [5, 6, and 7].

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Figure 12: Classification of titanium alloys with mechanical properties [3]

7. Applications

The application of titanium alloys can be seen across a wide spectrum. Although they are largely used in the aerospace industry (Figure 14), other market sectors are now beginning to adopt titanium in their various applications such as in medical devices, construction engineering and for automotive components (Figure 13) [3].



Figure 13: Applications of titanium alloys [3]

Figure14 shows the breakdown of titanium and its alloys in the aircraft and aviation industry, which is further subdivided into airframe and engine materials (Figure15). In (table 2.) the most common titanium forging alloys are listed [3].



Figure 14: Titanium alloys used in aerospace, and compared to other materials [3]

Titanium is a high strength to weight ratio, with only 60% of the density of steel, better corrosion resistance than stainless steel, low thermal conductivity, and high strength at 55% of the modulus strength of stainless steel [8].



Figure 15: Titanium alloys in aerospace [8]

Table 3 shows the Alloy Composition (ASTM Grade) of titanium, alloy description and the typical applications [6, 9].

Alloy Composition (ASTM Grade) Alloy Description [Common name]	Alloy Description	Typical Applications
	Commercially Pure (unalloyed) Ti	Grades
Ti Grade 1	Lower strength, softest, unalloyed Ti grade with highest ductility, cold formability, and impact toughness, with excellent resistance to mildly reducing to highly oxidizing media with or without chlorides and high weldability.	Anode/cathode/cell components, Consumer products (watches, eye glass frames, etc.), Chemical processing equipment, Desalination, brine concentration/evaporation, Hydrometallurgical extraction/ electro winning, Hydrocarbon refining/processing, Food processing/pharmaceutical, Medical implants/devices, surgical instruments, Pulp/paper bleaching/washing equipment, Navy ship components
Ti Grade 2	Moderate strength unalloyed Ti with excellent weldability, cold formability, and fabricability; "workhorse" and "garden variety" Ti grade for industrial service with excellent resistance to mildly reducing to highly oxidizing media with or without chlorides. Approved for sour service use under the NACE MR-01- 75 Standard.	Anode/cathode/cell components, Aircraft ducting, hydraulic, tubing, misc., Air pollution control equipment, Architectural, roofing, Consumer products (watches, eye glass frames, etc.), Chemical processing equipment, Desalination, brine concentration/evaporation, Food processing/pharmaceutical, Hydrometallurgical extraction/ electro winning, Hydrocarbon refining/processing, Medical implants/devices, surgical instruments, Navy ship components, Pulp/paper bleaching/washing equipment, Power plant cooling system components, Offshore hydrocarbon production/drilling, Sports/recreational equipment

Table 2: A Guide to Commercial Titanium Alloys [6]

Ti Grade 3	Slightly stronger version of Gr. 2 Ti with similar corrosion resistance with good weldability and reasonable cold formability/ductility.	Chemical processing equipment, Navy ship components, Power plant cooling system components
Ti Grade 4	Much stronger, high interstitial version of Grades 2 and 3 Ti with reasonable weldability, and reduced ductility and cold-formability.	Anode/cathode/cell components, Aircraft ducting, hydraulic, tubing, misc., Chemical processing equipment
	Commercially Pure Grades Modified W	Vith Pd or Ru
Ti-0.15Pd (Grade 7) [Ti-Pd]	Most resistant Ti alloy to corrosion in reducing acids and localized attack in hot halide media, with physical/mechanical properties equivalent to Gr. 2 Ti, and excellent weldability/fabricability.	Anode/cathode/cell components, Air pollution control equipment, Chemical processing equipment, Desalination, brine concentration/evaporation, Hydrometallurgical extraction/ electro winning, Pulp/paper bleaching/washing equipment
Ti-0.15Pd (Grade11)	Most resistant Ti alloy to corrosion in reducing acids and localized attack in hot halide media, with physical, mechanical, formability properties equivalent to Gr. 1 Ti (soft grade) and excellent weldability.	Anode/cathode/cell components, Chemical processing equipment, Desalination, brine concentration/evaporation, Hydrometallurgical extraction/ electro winning, Hydrocarbon refining/processing, Pulp/paper bleaching/washing equipment
Ti-0.05Pd (Grade16)	Lower cost, leaner Pd version of Ti Gr. 7 with equivalent physical/mechanical properties, and similar corrosion resistance. Tubing, Welded Pipe	Anode/cathode/cell components, Air pollution control equipment, Chemical processing equipment, Desalination, brine concentration/evaporation, Hydrometallurgical extraction/ electro winning, Hydrocarbon refining/processing, Pulp/paper bleaching/washing equipment
Ti-0.05Pd (Grade17)	Lower cost, leaner Pd version of Ti Gr. 11 with equivalent physical/mechanical properties and fabricability (soft grade) and similar corrosion resistance. Tubing, Welded Pipe	Anode/cathode/cell components, Chemical processing equipment, Desalination, brine concentration/evaporation, Hydrometallurgical extraction/ electro winning, Hydrocarbon refining/processing, Pulp/paper bleaching/washing equipment
Ti-0.1Ru (Grade 26 [TiRu-26]	A Lower cost, Ru-containing alternative for Ti Gr. 7 e)with equivalent physical/mechanical properties, fabricability, and similar corrosion resistance. Tubing, Welded Pipe b	Anode/cathode/cell components, Air pollution control quipment, Chemical processing equipment, Desalination, brine concentration/evaporation, Iydrometallurgical extraction/ electro winning, Iydrocarbon refining/processing, Pulp/paper leaching/washing equipment
Ti-0.1Ru (Grade 27 [TiRu-27]	Lower cost, Ru-containing alternative for Ti Gr. 11 with equivalent physical/mechanical properties (soft grade), fabricability, and similar corrosion resistance.	anode/cathode/cell components, Chemical processing quipment, Desalination, brine oncentration/evaporation, Hydrometallurgical xtraction/ electro winning, Hydrocarbon efining/processing, Pulp/paper bleaching/washing quipment
Alpha and Near- Alpha	Alloy	
Ti-0.3Mo-0.8Ni (Grad 12) [Ti-12]	Highly weldable and fabricable Ti alloy offering c improved strength and pressure code design allowables, hot brine crevice corrosion, and reducing acid resistance compared to Ti Grades 1, 2, and 3. Approved for sour service use under the NACE MR- 01-75 Standard.	Chemical processing equipment, Desalination, brine oncentration/evaporation, Geothermal brine energy xtraction, Hydrometallurgical extraction/ electro vinning, Hydrocarbon refining/processing, Offshore ydrocarbon production/drilling

	Medium strength, non-ageable 11 alloy offering	
Ti-3Al-2.5V	highest strength and design allowables under the	Aircraft ducting, hydraulic, tubing, misc., Consumer
(Grade 9)	pressure vessel code, with good weldability and cold	products (watches, eye glass frames, etc.), Navy ship
[Ti-3-2.5]	fabricability for mildly reducing to mildly oxidizing	components, Sports/recreational equipment
	media.	
Ti 3A1 2 5V Dd (Grada	Pd-enhanced version of Ti-3Al-2.5V with equivalent	Chemical processing equipment, Geothermal brine
18)	physical and mechanical properties and fabricability,	energy extraction, Hydrometallurgical extraction/
$[Ti_3_2 5_Pd]$	offering elevated resistance to dilute reducing acids	electro winning, Offshore hydrocarbon
[11-3-2.3-1 u]	and crevice corrosion in hot halide (brine) media.	production/drilling, Hydrocarbon production/drilling
	Ru-enhanced version of Ti-3Al-2.5V with equivalent	
Ti 2A1 2 5V Du(Grade	physical and mechanical properties and fabricability,	Chemical processing equipment, Geothermal brine
11-3A1-2.3 V-Ku(Olaue	offering elevated resistance to dilute reducing acids	energy extraction, Hydrometallurgical extraction/
$[T; 2, 2, 5, D_{\rm H}]$	and crevice corrosion in hot halide (brine) media.	electro winning, Offshore hydrocarbon
[11-3-2.3-Ku]	Approved for sour service use under the NACE MR-	production/drilling, Hydrocarbon production/drilling
	01-75 Standard.	
Ti-5Al-2.5Sn	Weldable, non-ageable, high-strength alloy offering	
(Grade 6)	good high temperature stability, strength, oxidation	Gas turbine engine components

[Ti-5-2.5]

Ti-5Al-2.5Sn ELI [Ti-5-2.5 ELI]	Extra low interstitial version of Ti-5Al-2.5Sn exhibiting an excellent combination of toughness and strength at cryogenic temperatures; suited for cryogenic vessels for service as low as -255°C.	Space vehicles/structures, missile components
Ti-8Al-1Mo-1V [Ti-8-1-1]	Highly creep-resistant, non-ageable, Weldable, high strength Ti alloy for use up to 455°C; exhibiting the lowest density and highest modulus of all commercial Ti alloys.	Gas turbine engine components
Ti-6Al-2Sn-4Zr-2Mo- 0.1S [Ti-6-2-4-2-S]	Weldable, high strength Ti alloy offering excellent strength, stability, and creep resistance to temperatures as high as 550°C.	Airframe components, Automotive components, Gas turbine engine components
Alpha- Beta Alloys		
Ti-6Al-4V (Grade 5) [Ti-6-4]	Heat treatable, high-strength, most commercially available Ti alloy ("workhorse" alloy for aerospace applications), for use up to 400°C offering an excellent combination of high strength, toughness, and ductility along with good weldability and fabricability.	Aircraft ducting, hydraulic, tubing, misc., Airframe components, Automotive components, Ballistic armor, Consumer products (watches, eye glass frames, etc.), Gas turbine engine components, Hydrometallurgical extraction/ electro winning, Landing gear components, Navy ship components, Hydrocarbon production/drilling, Sports/recreational equipment, Space vehicles/structures, missile components
Ti-6Al-4V ELI (Grade 23) [Ti-6-4 ELI]	Extra low interstitial version of Ti-6Al-4V offering improved ductility and fracture toughness in air and saltwater environments, along with excellent toughness strength, and ductility in cryogenic service as low as -255°C. Typically used in a non-aged condition for maximum toughness.	Airframe components, Medical implants/devices, surgical instruments, Ballistic armor, Navy ship components, Offshore hydrocarbon production/drilling, Space vehicles/structures, missile components
Ti-6Al-4V-0.1Ru (Grade 29) [Ti-6-4-Ru]	Extra low interstitial, the Ru-containing version of Ti-6Al-4V offering improved fracture toughness in air, seawater, and brines, along with resistance to localized corrosion in sweet and sour acidic brines as high as 330°C. Approved for sour service use under the NACE MR-01-75 Standard.	Chemical processing equipment, Desalination, brine concentration/evaporation, Geothermal brine energy extraction, Offshore hydrocarbon production/drilling, Hydrocarbon production/drilling

Ti-6Al-4V-0.1Ru (Grade 29) [Ti-6-4-Ru]	Extra low interstitial, the Ru-containing version of Ti-6Al- 4V offering improved fracture toughness in air, seawater, and brines, along with resistance to localized corrosion in sweet and sour acidic brines as high as 330°C. Approved for sour service use under the NACE MR-01-75 Standard.	Chemical processing equipment, Desalination, brine concentration/evaporation, Geothermal brine energy extraction, Offshore hydrocarbon production/drilling, Hydrocarbon production/drilling
Ti-6Al-7Nb	High strength Ti alloy with good toughness and ductility, used primarily for medical implants stemming from its excellent biocompatibility.	Medical implants/devices, surgical instruments
Ti-6Al-6V-2Sn Ti-6-6-2]	Heat treatable, and high strength Ti alloy with higher strength and section hardenability than Ti-6Al-4V, but with lower toughness and ductility, and limited weldability. Can be used in mill annealed or in the aged (very high strength) condition.	Airframe components
Ti-6Al-2Sn-4Zr-6Mo [Ti-6-2-4-6]	Heat-treatable, deep-hardenable, very high strength Ti alloy with improved strength to temperatures as high as 450°C, with limited weldability. Approved for sour service under the NACE MR-01-75 Standard.	Gas turbine engine components
Ti-4Al-4Mo-2Sn-0.5Si [Ti-550]	Heat-treatable, high strength forging alloy with good strength and creep resistance to temperature as high as 400°C.	Gas turbine engine components
Ti-6Al-2Sn-2Zr-2Mo- 2Cr-0.15Si [Ti-6-22-22]	Heat-treatable, high strength Ti alloy with strength and fracture toughness- to-strength properties superior to those of Ti-6Al-4V, with excellent superplastic formability and thermal stability.	Airframe components, pace vehicles/structures, missile components
Ti-4.5Al-3V-2Mo-2Fe [SP-700]	Heat-treatable, high strength Ti alloy with superior strength and exceptional hot and superplastic formability compared to Ti-6Al-4V, combined with good ductility and fatigue resistance.	Airframe components, Consumer products (watches, eye glass frames, etc.), Gas turbine engine components, Sports/recreational equipment, Space vehicles/structures, missile components
Ti-5Al-4Cr-4Mo-2Sn- 2Zr [Ti-17]	Heat-treatable, deep section hardenable, very high strength Ti alloy with superior strength and creep resistance over Ti-6Al-4V to temperatures as high as 400°C, and limited weldability.	Gas turbine engine components
Near-Beta and Beta All	loys	
11-10V-2Fe-3AI	Heat-treatable, deep hardenable, very high strength 11	Airframe components, Landing gear components

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[Ti-10-2-3]	alloy possessing superior fatigue and strength/ toughness
	combinations, with exceptional hot-die forgeability, but
	limited weldability.
	A heat-treatable, deep section hardenable, very high
Ti-3Al-8V-6Cr-4Zr-	strength Ti alloy possessing good toughness/strengthGeothermal brine energy extraction, Landing gear
4Mo	properties, low elastic modulus and elevated resistance to components, Navy ship components, Hydrocarbon
(Grade 19)	stress and localized corrosion in high temperature sweet production/drilling, Space vehicles/structures, missile
[Ti Beta-C™]	and sour brines. Approved for sour service under the components
	NACE MR-01-75 Standard.
Ti-3Al-8V-6Cr-4Zr-	A Pd-containing version of the Ti-38644 alloy (Beta-C/Pd)
4Mo-0.05Pd	possessing equivalent physical/mechanical properties, but Geothermal brine energy extraction, Navy ship
(Grade 20)	with significantly enhanced resistance to stress and components, Hydrocarbon production/drilling
[Ti Beta-C/Pd]	localized corrosion in high temperature brines.

8. Properties

Titanium and its alloys are well-established for their combination of relatively high strengths, low densities, and superb corrosion resistance. Yield strengths are in a range from 480 MPa for some grades of commercial titanium to approximately 1100 MPa for structural alloys. Added to their static strength advantage is the fact that titanium alloys have much better fatigue strength than the other lightweight alloys, such as those of aluminum and magnesium.

Titanium and its alloys can be used at moderately elevated temperatures which depend on the given alloy (Table 4). Some α -titanium alloys, especially the low interstitial grades, are also useable in cryogenic applications because they do not display any ductile-to-brittle transition. What is shown next is an overview of the most frequently encountered titanium alloys and pure grades, their properties, benefits, and industry applications [7].

Alloy	Chemical Composition [wt. %]	Τβ [oc]	Hardness [HV]	E {GPa]	YS [MPa]	TS [MPa]	%El	KIc [MPa m1/2]
α Titanium Alloys high purity Ti	99.98 Ti	882	100	100-145	140	235	50	
Grade 1	(cp Ti: 0.2Fe, 0.180)	890	120		170-310	<240	24	
Grade 4	(cp Ti: 0.5Fe, 0.400)	950	260	100-120	480-655	<550	15	
Grade 6	(Ti-5Al-2.5 Sn)	1040	300	109	827	861	15	70
Near-α Titanium All	oys							
Ti-6-2-4-2-S	Ti-6Al-2Sn-4Zr-2Mo-0.1Si	995	340	114	990	1010	13	70
TIMETAL 1100	Ti-6Al-2.7Sn-4Zr-0.4Mo- 0.4Si	1010		112	900-950	1010-1050	10-16	60-75
TIMTETAL 685	Ti-6Al-5Zr-0.5Mo-0.25Si	1020		120	850-910	990-120	6-11	68
TIMETAL 834	Ti-5.8Al-4Sn-3.5Zr-0.5Mo- 0.7Nb-0.35Si-0.06C	1045	350	120	910	1030	6-12	45
α +βTitanium Alloys	5				<u>.</u>			
(Grade 5) [Ti-6-4]	Ti-6Al-4V	995	300-400	110-140	800-1100	900-1200	13-16	33-110
Ti-6-6-2	Ti-6Al-6V-2Sn	945	300-400	110-117	950-1050	1000-1100	10-19	30-70
Ti-6-2-2-2-2	Ti-6Al-2Sn-2Zr-2Mo-2Cr- 0.25Si			110-120	1000-1200	1100-1300	8-15	65-110
Ti-6-2-4-6	Ti-6Al-2Sn-4Zr-6Mo	940	330-400	114	1000-1100	1100-1200	13-16	30-60
Ti-17	Ti-5Al-2Sn-2Zr-4Mo-4Cr	890	400	112	1050	1100-1250	8-15	30-80
Metastable β Titaniu	m Alloys				<u>.</u>			
SP 700	Ti-4.5Al-3V-2Mo-2Fe	900	300-500	110	900	960	8-20	60-90
Beta III	Ti-11.5Mo-6Zr-4.5Sn	760	250-450	83-103	800-1200	900-1300	8-20	50-100
(Grade 19) Beta C	Ti-3Al-8V-6Cr-4Mo-4Zr	795	300-450	86-115	800-1200	900-1300	6-16	50-90
Ti-10-2-3	Ti-10V-2Fe-3Al	800	300-470	110	1000-1200	1000-1400	6-16	30-100
Ti-15-3	Ti-15V-3Cr-3Al-3Sn	760	300-450	80-100	800-1000	800-1100	10-20	40-100

Table 4: Mechanical	properties of titanium alloys [[3]
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9. Conclusion

- 1. It is a fact that titanium is not a rare substance as it ranks the ninth most plentiful element and the fourth most abundant structural metal located in the Earth's crust, which is exceeded only by aluminum, iron, and magnesium. It is rarely found in high concentrations and never discovered in a pure state.
- 2. The types and quantity of alloying elements make specific the type of titanium alloy.
- 3. The issue that rises with the titanium and its alloys is sustaining the titanium without the metal phase changed, due to the temperature increase
- 4. Due to the physical and mechanical properties, titanium boasts off many benefits for instance high melting temperature and lightweight compared with steel, which has expanded uses.

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5. Titanium (Ti-6Al-4V) alloy is mostly often used titanium alloy since it is known to have the best property balance.

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