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A Comparative Study of Aluminium Alloy and Titanium Alloy

Comparison of AL-7175 alloy and Ti6Al4V alloy (Literature Survey Paper)

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Abstract— About 50% of metals used in Aerospace industries are Aluminium and Titanium alloys, Alloys such as Ti6Al4V, AL-7175, and AL-7075 are used extensively in space vehicles, aviation, and automotive industries for having enhanced mechanical properties like High strength to weight ratio, low Thermal Expansion and better Corrosion resistance. Comparison of properties Aluminium and Titanium alloys shows the importance of lightweight alloys having better strength which satisfies the needs of aviation industries.

Keywords- *Titanium alloys, Aluminium alloys, AL-7175, Ti6Al4V.*

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I. INTRODUCTION

Aluminium is the third most abundant material in earth, having low density, relatively soft, durable, lightweight, ductile malleable, better strength and cost effective, still it's properties are comparably lower than Titanium and its Alloys [1].

Titanium alloys primarily stand out due to two properties: high specific strength and excellent corrosion resistance. This also explains their preferential use in the aerospace sector, the chemical industry and medical engineering; at higher temperatures the specific strength of titanium alloys is particularly attractive. However, the maximum application temperature is limited by their oxidation behavior [2].

II. LITERATURE SURVEY

The Improved Elevated Temperature charecteristics of Titanium alloys combined with their high strength to weight ratios make them an attractive alternative to Nickel base super alloys for certain gas Turbine components. Titanium alloys possess a weight reduction advantage of approximately 40% over their Nickel base counterparts [3]. Titanium has come to be used for some parts of mass-produced automobiles by taking advantage of lightweight and high strength. It is necessary, however, to solve many problems still more for further utilization of this metal. One of them is the drastic reduction in cost of titanium which still looks like a high grade material in spite of the recent cost reduction.

Generally, Ti-6Al-4V is used in applications up to 400 degrees Celsius. It has a density of roughly 4420 kg/m3, Young's modulus of 115 GPa, and tensile strength of 1000 Mpa [3] By comparison, annealed type 316 stainless steel has a density of 8000 kg/m3, modulus of 193 GPa, and tensile strength of only 570 Mpa [4].

A. Phase Diagram of Aluminium and Titanium Alloys:

Microstructure of alloys can be varied significantly in the processes of plastic working and heat treatment allowing for fitting their mechanical properties including fatigue behaviour to the specific requirements.

Ti-6Al-4V – martensitic α+β alloy (K_β = 0.3) – is the most widespread titanium alloy (>60% of all titanium alloys produced in USA and EU). Its high applicability results from good balance of mechanical properties and good castability, plastic workability, heat treatability and weldability. Aluminium addition stabilizes and strengthen α phase, increases α+β↔β transformation temperature and reduces alloy density. Vanadium – β-stabilizer – reduces α+β↔β transformation temperature and facilitates hot working [5].

Figure 1: Beta Stabilizing Elements is Titanium.[6]

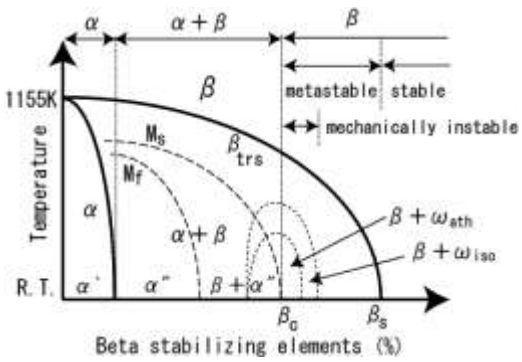
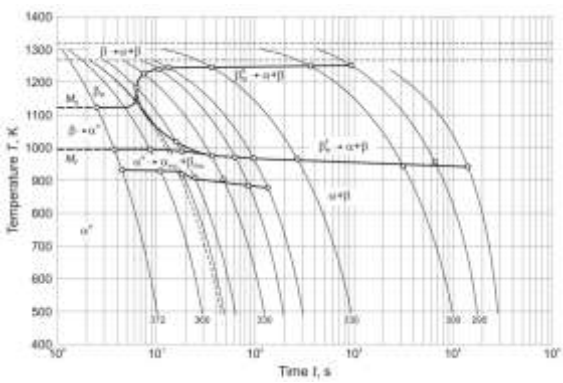


Figure 2: TTT Curve for Titanium Alloys.



Since there are no allotropic phase transformations in aluminium, much of the control of microstructure and properties relies on precipitation reactions. The solubility of solute in the matrix α is therefore of importance. This solubility cannot be defined in isolation –it depends on the phase with which α is in equilibrium. In the Al–Cu system, the stable precipitate is CuAl2 but because it is difficult to nucleate, metastable GP1 zones form first. Thus, the free energy curve for GP1 zones is located above that for CuAl2.

Figure 3: Phase Diagram of Aluminium Alloy

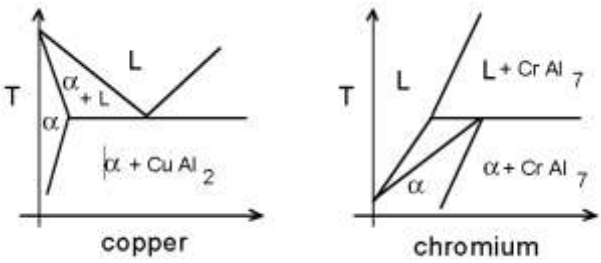
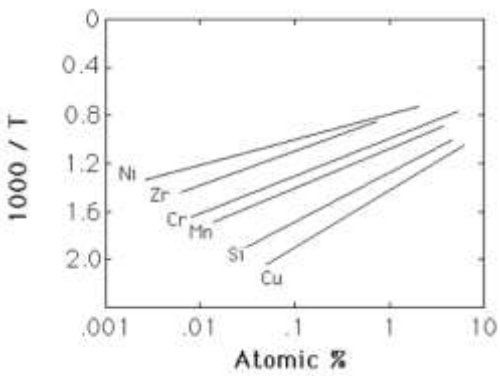


Figure 4: Solubility of a variety of solutes in aluminium.



B. Mechanical Properties of Aluminium and Titanium Alloys

Both Aluminium and Titanium alloys are used extensively in aerospace industries for having the properties such as Corrosion resistance, Low density, High strength to weight ratio, Low modulus of Elasticity, Non-Magnetic, low Thermal Expansion. Below table shows comparison of mechanical properties of three alloys which are extensively used in aerospace industries.

Table 1: Comparison of mechanical properties of Aluminium and titanium alloys [7] [8] [3].

Alloy	Mechanical Properties			
	Yield strength (Mpa)	*Tensile Strength (Mpa)*	*Elongation (%)*	*Modulus of Elasticity (Gpa)*
7075_T7351	435	505	13	71
7175_T7351	517	565	11	75
Ti-6Al-4V	1103	1172	10	113

C. Composition of Aluminium and Titanium Alloys

Aluminium and Titanium is alloyed with various elements such as Copper, Magnesium, Manganese, Silicon, Zinc Scandium, Vanadium, Cobalt and Nickel to obtain the desired properties, as shown in Table 2 for Al-7175, Al-7050 and Table 3 for Ti6Al4V.

Table 4: Chemical Composition of Aluminium alloys (7050 & 7175) [9][10].

Alloy	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Zr	Al
6060	0.40	0.55	0.18	0.04	0.06	0.007	0.02	0.02	-	Balance
7050	2.42	0.28	0.19	1.76	0.07	-	6.15	0.06	0.14	Balance
7175	2.54	0.05	0.18	1.57	0.05	0.22	6.4	-	-	Balance

Table 5: Chemical Composition of Titanium alloy (Ti6Al4V) [11][12].

ALLOY	Al	V	Zr	Si	Fe	N	H	Ti
Ti6Al4V	6.46	3.84	0.02	0.01	0.083	0.003	0.003	Balance

D. Cost of Aluminium and Titanium Alloys:

Cost of the most widely used structural alloys such as AL-7075_T7351, AL-7175_T7351 and Ti-6Al-4V are stated in below Tabel-4 as per London Metal Exchange(10Aug2015) .

Table 6: Cost of Aluminium and Titanium Alloys

Alloy	Cost per Kg		Cost per lb	
	US-$	*INR*	*US-$*	*INR*
AL-7075_T7351	1.84	110	0.83	49.8
AL-7175_T7351	2.20	130	0.98	58.89
Ti-6Al-4V	18.75	506	8.5	1117

E. Effects of alloying elements on properties of aluminum alloys:[13][14]

Function of Alloying elements is to increase the alloy strength (Pure Aluminium has low strength of < 60 Mpa) [15].

Alloying elements when added to Aluminum alloys produces effects of precipitation hardening (age hardening), solid solution hardening, dispersion strengthening, grain refining, modifying metallic and inter-metallic phases, suppression of grain growth at elevated temperatures (e.g. during annealing),wear resistance and other tribological properties.

Majority of four alloying elements are used such as Mg, Zi, Cu, and Si and these elements are called as basic or principal alloying elements. Large amounts of principal alloying elements are alloyed because of their Solubility in Aluminium. It is known that maximum solubility exceeds 1% only in seven elements such as Mg, Cu, Si, Li, Mn, Ge, and Ag. [15]

1. Silicon (Si): Improves castability, resistance to abrasive wear, Increases Strength. Silicon in a combination with magnesium allows strengthening the alloys by precipitation hardening.

2. Copper (Cu): Increases tensile strength, fatigue strength and hardness of the alloys due to the effect of solid solution hardening. Decreases corrosion resistance and Ductility of alloy.
3. Magnesium (Mg): Strengthens and hardens the alloys by solid solution hardening without considerable decrease of ductility.
4. Manganese (Mn): Increases corrosion resistance. Improves low cycle fatigue resistance and ductility of aluminum alloys
5. Boron (B): Boron in a combination with titanium refines primary aluminum grains (grains formed during the Solidification) due to formation of fine nuclei TiB2.

F. Effects of alloying elements on properties of Titanium alloys: [16]

Alloys containing 4 to 6% of beta stabilizers are called α+β alloys (Ti-6Al-4V and Ti-6Al-6V-2Sn). Al, Sn are α Stabilizers and V, Mo, Cr, Cu, Ni, Zi, are β Stabilizers, Silicon with 0.005 to 1% of wt Improves Creep Resistance.
The Strength at room temperature increases with increase in Zr and Sn contents. Tin is more effective than Zr, While Nb, Ta and Pd are less effective. The tensile strength of Ti-15%Sn-4%Nb-2%Ta-0.2%Pd alloy (990 Mpa) is higher than ASTM Specification value of Ti-6Al-4V (860 Mpa) [17].
With the increasing element V content or decreasing element Cr content the thermal stability becomes better, which is due to different solution characteristic of element V and Cr in titanium alloy [18] [19].

1. Aluminium (Al): A α Stabilizer increases tensile and creep strengths and moduli, while reducing alloy density.The maximum solid solution strengthening achieved by Aluminium is about 7% , as it possess ordering and Ti_3Al formation with embrittlement [3].
2. Ti (Sn): is less potent α Stabilizer and solid solution strengthening in conjunction with Aluminium to achieve higher strength without embrittlement.
3. Zirconium (Zi): It forms a weak β stabilizer. It increases strength at low and medium temperature, the use of Zi above 5 to 6% reduces ductility and creep resistance.
4. Silicon (Si): is an important element in high temperature Titanium alloys, since it increases strength at all temperature and has a marked beneficial effect on creep resistance.
5. Niobium (Ni): This is also a β stabilizer, is added primarily to improve surface stability during high temperature exposure.

G. Application of Aluminium and Titanium Alloys

Aluminium is most widely used metal in all Industries such as Aerospace, Automotive, Marine Rail Building, Packaging, Mechanical industry and engineering, Energy distribution, Sports and leisure. Aluminium and its alloys provide excellent resistance to atmospheric corrosion in marine, urban and industrial settings. This high resistance extends the life of equipment, significantly reduces maintenance costs and preserves outward appearances. These properties are especially desired in industrial vehicles, street furniture and traffic signals.

Alloy Al-7175 is typically utilized in applications where improved formability and toughness are desired

Titanium alloy is extensively used in Blades, discs, rings, airframes, fasteners, components. Vessels, cases, hubs, forgings. Biomedical implants [20].

H. Figures.

Figure 5: Stress-Strain Curves of Aluminium in Comparison with Various Metals and Alloys [21].

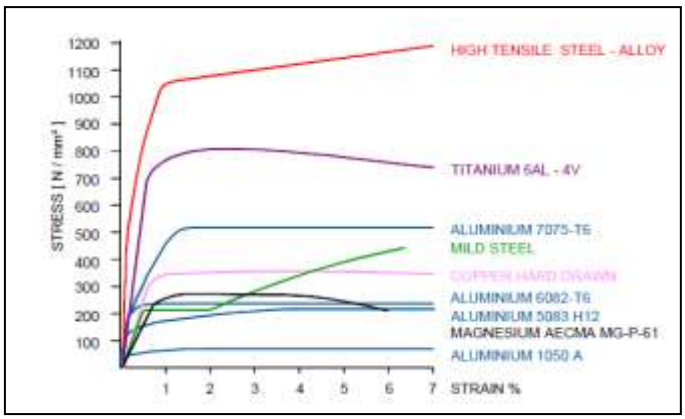
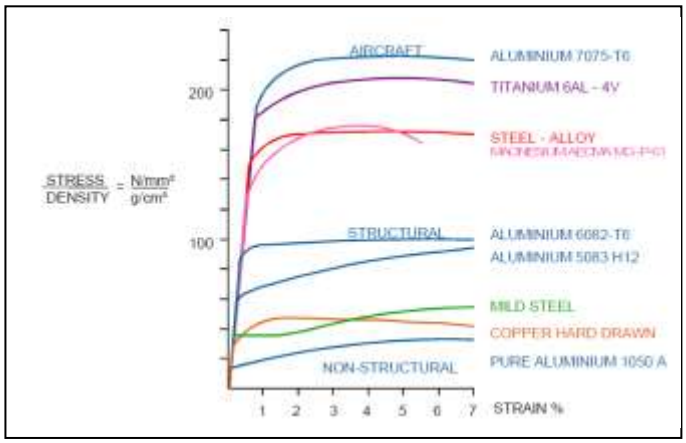


Figure 6: Density-Related Strength of Aluminium in Comparison with Various Metals and Alloys [21][20].



III. Conclusion

From the above survey, by comparing the properties of Aluminium alloy (AL-7175) and Titanium Alloy (Ti-6Al-4V), both Aluminium and Titanium alloy has better Mechanical properties. Therefore selection of materials is purely based on the application and cost effectiveness.

If low density and cost effectiveness is the essential parameter Al-7075 is chosen, and if low density with improved strength and toughness is required Al-7175 is chosen, If cost is not the parameter and require a better strength, toughness and corrosion resistance, alloy Ti-6Al-4V is selected.

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