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Titanium: Metal of 21st Century

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Abstract— *Due to continuous increase in fuel price automobile manufacturers are switching to light weight materials. Titanium (Ti) is superior in terms of strength and density when compared with currently used materials in automobiles. This paper highlights distinct properties of Titanium over those materials. Latest cost effective machining methods and major applications of Titanium in automobile parts are mentioned in subsequent pages.*
Keywords— Automobiles, Density, Fuel Price, Strength, Titanium.

I. INTRODUCTION

In 1791, British mineralogist and chemist William Gregor discovered Titanium. It is fourth most abundant structural metal available in Earth's crust. But rarely Ti found in its pure form, So extraction of Ti is costly process and thus it is carried out in batch. Ilmenite and two TiO_2 polymorphs (rutile and anatase) are economically important Ti minerals. Due to high refractive index rutile is most desirable[1]. Today more than 100 Ti alloys are available which allows design engineer to select an alloy having required set of properties as per application. When compared with currently used materials in automotive industry Ti has several excellent properties[2]. Following table compares these widely used materials with Ti[3].

Table 1: Comparison of Ti alloys with other metals

	Specific gravity	Young's modulus (GPa)	Tensile strength (MPa)	Corrosion resistance
Steel	7.85	205	400-800	Poor
Stainless steel	7.95	200	600	Good
Ti alloy	4.43	114	900	Excellent
Al alloy	2.70	70	250	Poor
Mg alloy	1.70	45	200	Poor

Following figure gives brief idea about characteristic properties of Ti which makes it most suitable for automotive industry[4]

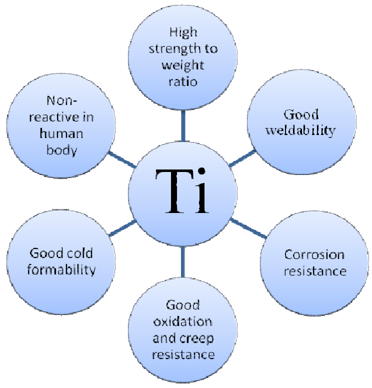

Fig.1: Characteristics of Titanium

Chemical composition and microstructure are responsible for determining properties of Ti alloys. Depending on influence of alloying elements on β-tranus temperature, Ti alloys are classified as α, β and α+β alloys.

Table.2: list of α and β-stabilizing elements

α-stabilizing elements	β-stabilizing elements
Aluminum Oxygen Nitrogen Carbon	Molybdenum Iron Vanadium Chromium Manganese Silicon
Tin and Zirconium are neutral elements	

Effect of α-stabilizing elements is that they extends α phase towards high temperatures whereas β-stabilizing elements shifts β phase towards low temperatures. Neutral elements have very little influence on β-tranus temperature[5].

Table.3:Characteristics of α and β Titanium alloys

α-Titanium alloys	β-Titanium alloys
Excellent corrosion resistance Good cold formability	High strength to weight ratio High fatigue strength Higher toughness Poor low and high temperature properties Complex microstructure

II. ADVANCED MACHINING AND PROCESSING OF TI ALLOYS

Arc melting is conventional method for processing Ti alloys. In this electric current is pass in between electrode tip and Ti is placed over Cu crucible, as Ti offers resistance to electric current heat gets generated and Ti melts. This process is somewhat costly so different processes are developed in subsequent years[6].

Powder metallurgy is also one of the better processing method for Ti alloys. In this instead of melting Ti is transformed into powder. Then applying required pressure and carrying out sintering operation final products are formed[7]. With this method it is possible to produce intricate shaped components of excellent surface finish. Powder metallurgy leads to uniform grain structure and improves homogeneity of final product[8].

Widely used Ti alloy Ti 6Al 4V has excellent castability hence investment casting is also one of the possible production method. Product obtained after investment casting with subsequent thermo-mechanical process has strength equivalent to that of mechanically worked component. It is observed that resistance to crack propagation gets improved which increase fatigue life of product. As there is no removal of material so it adds further benefit of saving of material[9].Ti alloys have poor machinability. It causes large quantities of wastage of material. Special tools developed for machining of Ti alloys are costly but they can reduce overall cost of machining[10].

III. APPLICATIONS OF TI IN AUTOMOTIVE INDUSTRY

Although it takes very long for commercialization of Ti in automotive industry, currently Ti has good share of total automobile parts. Following figure shows scope for application of Ti in automotive industry[11].

Fig.2: Scope of Ti alloys in automobiles

Following table gives brief information about usage of Ti alloys for various automobile parts by different automobile manufacturers all over the World[11]

Table.5: Summery of application of Ti alloys in automobile

Year	Component	Material	Manufacturer	Model
1992	Connecting rods	Ti-3Al-2V-rare earth	Honda	Acura NSX
1994	Connecting rods	Ti-6Al-4V	Ferrari	All 12-cyl.
1996	Wheel rim screw	Ti-6Al-4V	Porsche	Sport wheel option
1998	Brake pad guide pins	Ti grade 2	Daimler	S-Class
1999	Connecting rods	Ti-6Al-4V	Porsche	GT3
1999	Valves	Ti-6Al-4V & PM-Ti	Toyota	Altezza 6-cyl.
2000	Suspension springs	TIMETAL LCB	Volkswagen	Lupo FSI
2000	Wheel rim screw	Ti-6Al-4V	BMW	M-Techn. option
2000	Valve spring retainers	β-titanium alloys	Mitsubishi	All 1.8 l – 4-cyl.
2001	Wheel rim screw	Ti-6Al-4V	Volkswagen	Sport package GTI
2002	Valves	Ti-6Al-4V & PM-Ti	Nissan	Infiniti Q45
2003	Suspension springs	TIMETAL LCB	Ferrari	360 Straddle

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Ti alloys found large applications in engine parts, suspension springs, exhaust pipe and mufflers. Engine parts such as valves, valve springs, retainers and connecting rods[12]. Mitsubishi used Ti-22 V-4 Al in AMG engine retainers due to its good cold forgeability. Honda made use of Ti-3Al-2.5V for connecting rods in their NSX racing car. Nissan motors used Ti-6Al-4V and Ti-6Al-2Sn-4Zr-2Mo-Si for inlet and exhaust valves respectively[3].

Among all engineering alloys Ti alloys have unique combination of strength, density and low shear modulus which makes it ideal material for springs[13]. Ti-6Al-4V, β-Titanium alloys and TIMETAL LCB (Low Cost Beta) are commonly used Ti alloys[14]. These springs are smaller and about 60% lighter than equivalent steel springs hence it saves space and lowers weight. Valve springs made up of Ti alloys reduces overall height of engine[15].

High class cars and bikes makes use of Ti alloys in exhaust pipe and muffler. In 1988 Kawasaki used Ti alloy in muffler of their sport bike ZX-9R. In similar way Honda CBR-900RR, Suzuki GSX-R1000, Yamaha YZF-R1 used Ti alloys to fabricate their mufflers. By adopting Ti alloys for mufflers approximately 40% weight reduction was achieved[16].

Fig.3: Application of Ti alloy in muffler and exhaust pipe

Apart from these, replacement of steel bolts and fasteners with Ti bolts and fasteners leads to significant reduction in weight. Ti fasteners are made by using powder metallurgy process[11][17].

IV. APPLICATION OF TI IN AEROSPACE INDUSTRY

Components made from Ti alloys are ideally suited for aerospace applications because of their unique set of properties like high strength to weight ratio over wide range of temperatures and excellent corrosion resistance in extreme conditions[15]. Generally in civil aircrafts CP (commercially pure) Ti grade 2, Ti 3Al 2.5V, Ti 6Al 4V, Ti 10V 2Fe 3Al and Ti 5Mo5Al 5V 3Cr alloys are used. Following figure demonstrates wide scope of Ti alloys in aerospace industry. It has about 35% share of total Ti usage. Military aircrafts like F-22, F/A-18, C-17 and UH-60 Black Hawk helicopter having significant amount of Ti alloys in their parts.

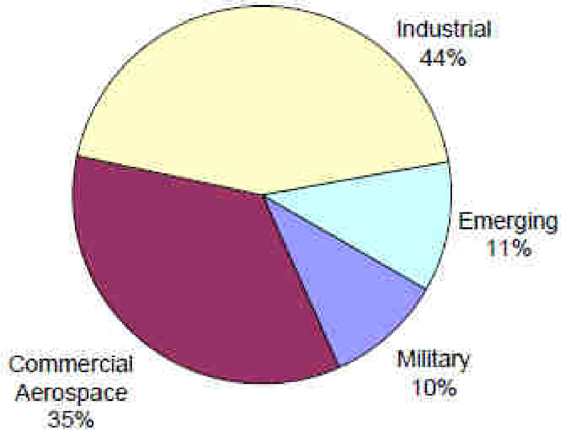

Fig.4: Schematic representation of Ti alloys in various fields

Ti alloys have good compatibility with carbon fiber reinforced polymers (CFRP) hence they have replaced earlier Al alloy parts which leads to heat and corrosion when comes in contact with CFRP. CFRPs used in aircrafts to reduce weight and improve fuel efficiency[18]. A good example of usage of Ti in this area is design of landing gear for Boeing 747 and 757. Earlier Al was selected for it due to its lower weight and cost but it is not able to sustain that load in required wing envelop. Steel was the better option but it increasing total weight of structure so engineers go for Ti alloy which simultaneously satisfies both strength and weight requirements. In aircraft support structure below galleys and lavatories subjected to very corrosive environment so to increase its corrosion resistance, it is constructed using Ti alloys which has excellent corrosion resistance and they don't required any protective coating or paints hence lowers weight of structure.

V. CONCLUSIONS

As weight reduction is necessary for improving fuel efficiency usage of Ti is increased in automotive sector in past ten years. Application of Ti was started in F1 racing cars but now it is also used in high class cars and bikes.

Titanium (Ti) has approximately equal strength as steel but it is 45% lighter than steel, Similarly Ti shows double strength than aluminum (Al) whereas it is only 60% heavier than Al. Hence it has great scope in automobiles.

Due to its distinct characteristics Ti is ideal material for design of springs operating under any conditions.

Lower weight and excellent corrosion resistance of Ti alloys makes it very useful in aerospace applications.

Costly extraction and processing methods put limits to the application of Ti in automobiles hence it is necessary to develop new cost effective methods.

To further increase usage of Ti in automobiles simultaneous efforts of Ti manufacturers and automobile manufacturers are required to develop cost effective methods of Ti production and processing.

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