TITANIUM APPLICATION IN AVIATION INDUSTRY OF CHINA

Chenggong Li and Jimin Ma

Institute of Aeronautical Materials
P.O.Box 81, Beijing, 100095 China

Abstract

After more than thirty years intensive research and development work, titanium application in the aviation industry of China is growing up with the increasing titanium industry of China. The application of both wrought and cast titanium alloys in aircrafts and aeroengines is described and future developments are indicated.

Introduction

As a critical structural material being served, titanium and its alloys have been widely used in aerospace industry. Since titanium possesses better performance than conventional structural materials, such as strength-to-weight ratio, corrosion resistance, heat resistance etc., the application of large-scale fan blades in aircraft jet engine becomes possible, owing to which the high thrust engine and the high mach number aircraft can be realized. It can be said without any exaggeration that development aviation industry has been advanced by making substantial progress in titanium alloys and their technology.

Since IMI 315 titanium alloy blades were used in the British Avon engine in 1954, the application of titanium in the aviation industry has been unceasingly expanded,the manufacturing technology is growing up and the quality control is being gradually improved. So far, scores of titanium alloys have been developed. Having been successfully developed in the U.S.A. during the early period, Ti-6Al-4V alloy became a universal structural material. By studying Si additions, the U.K. has made an outstanding contribution to developing a series of titanium alloys bearing silicon. For example, IMI 550(Ti-4Al-2Sn-4Mo-0.5Si) alloy allows the service temperature to rise up to 425^{o}C, while its strength is 10% higher than that of Ti-6Al-4V alloy. With the further studying of beta processing it has been found out that beta processing can provide higher creep strength and fracture toughness and less fatigue crack propagation rate than alpha+beta processing alloys, and can be used in long term service at 520^{o}C, such alloys as IMI 685(Ti-6Al-5Zr-0.5Mo- 0.25Si) and Ti5621S(Ti-

Titanium '92
Science and Technology
Edited by F.H. Froes and I. Caplan
The Minerals, Metals & Materials Society, 1993

5Al-6Sn-2Zr-0.8Mo-0.25Si). It has been noticed that the induced fatigue initiation always occurs in alpha phase,but for beta processing alloys it is located in grain boundary alpha or alpha colony of prior beta grain. Concerning IMI 829(Ti-5.5Al-3.5Sn-3Zr-1Nb-0.3Mo-0.3Si) alloy, on the one hand,it is fully considered that its creep-resistance can be improved by alloying,and on the other hand, beta grain size of final forging should be restricted as far as possible so that its maximum working temperature is increased up to 580^{o}C and it can be used in jet engine. Chinese scientists also have developed advanced titanium alloys such as ZT3 (Ti-5Al-5Mo-2Sn-0.25Si-0.02Ce) titanium cast alloy, which is contains rare-earth cerium,with service temperature of 500^{o}C and a new alloy, which contains neodymium and can be used at 550^{o}C temperature. Both alloys have been successfully used in aircraft engines of China.

Applications of wrought titanium alloys in aviation industry of China

The early stage of using titanium in China's aircraft engines was in the fifties to the sixties. In 1965 Ti-6Al-4V alloy was successfully used for the first, sixth, seventh,eighth and ninth stage rotor blades and disks of an early model jet engine compressor, owing to which the weight of 32 kg was saved for each engine. Since then, the application of titanium alloys such as Ti-6Al-4V, Ti-6.5Al-2Zr-3.5Mo-0.25Si (TC11) and Ti-5Al-2.5Sn have been expanded in various model jet engines and turbofan engines in succession.

Since the eighties, titanium alloy components including the third,fourth, fifth, sixth, seventh and eighth stage compressor rotor baldes and disks as well as corresponding stator baldes are fully used in the new generation of jet engines. In addition, the second to seventh stage four compressor cases made of titanium alloys such as Ti-6Al-4V alloy and ZT3 alloy bearing rare-earth cerium, the ring-shaped components and sheet-metal parts made of Ti-5Al-2.5Sn alloy and Ti-6Al-4V alloy fasteners (See Figs 1 and 2) are used for the above mentioned jet engine.

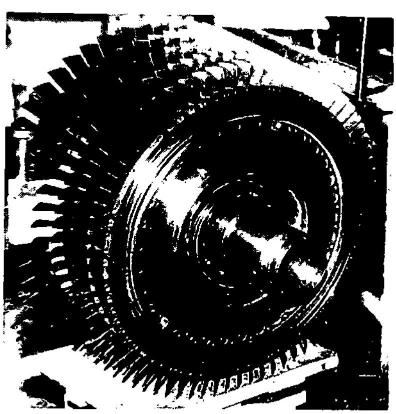

Fig.1 Titanium alloy compressor rotor

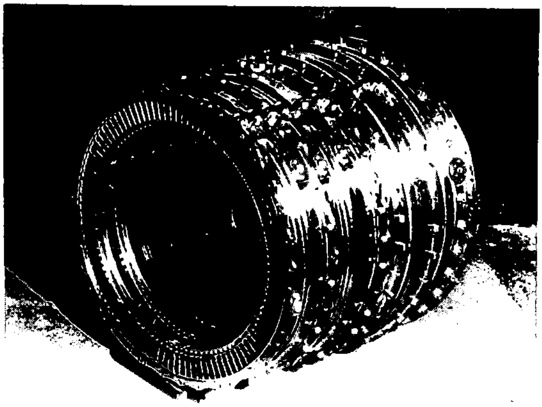

Fig.2 Titanium alloy compressor case assembly

Alpha+beta type heat-resistant titanium alloy of Ti-Al-Mo-Zr-Si system, titanium alloy possesses excellent properties of heat-resistance and thermal stability at 500°C. During the process of research and development of this alloy, the formation and varying rule of new beta grain has been explored and the alternative high-low temperature forging technology (AHLT) has been developed to improve the homogeneity of large-size forging structure. The isothermal forging of titanium alloy disks and the precision forging of titanium alloy blades (Fig.3) are widely used technologies in aircraft engine manufacture.

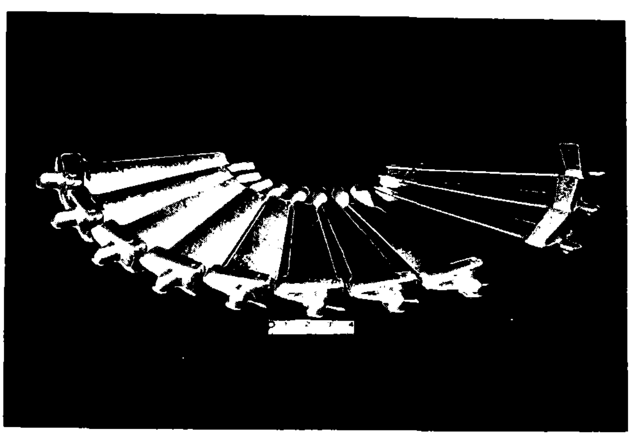

Fig.3 Precision forging titanium alloy (TC11) blades

Ti-6Al-4V alloy and Ti-10-2-3 alloy are used for some important load-bearing components such as aircraft frames and beams in order to save structure weight of modern model fighters. (See Fi.'.4). A Chinese forging company has already become a titanium forging supplier for Boeing Co., which provides Ti-6Al-4V alloy closed-die forgings in batch process used in Boeing 747 aircraft.

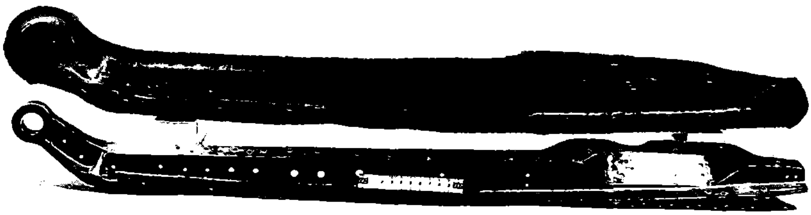

Fig.4 Ti-6Al-4V alloy aircraft forging

The theoretical study and technical development of titanium alloy superplastic forming-diffusion bonding (SPF/DB) has also begun to be used in important structure components, e.g. aircraft cabin doors, frames etc. as shown in Fig.5.

Fig.5 Titanium alloy SPF/DB aircraft components

Ti_3Al-based alloy(Ti-25Al-10Nb-3V-1Mo, at %), which is studied by Beijing Institute of Aeronautical Materials, is manufactured as forging bar, rolled bar, rolled ring, closed-die forging, sheet and foil. Their alloying compositions are uniform, the forging microstructure is fine and the mechanical properties are quite good e.g. room temperature tensile strength is 1050 MPa and elongation is 4-8 %. As shown in Fig.6, a turbine guide plate and a turbine connector ring made of Ti-25Al-10Nb-3V-1Mo alloy have been conducting in an engine test run for 30 hrs.

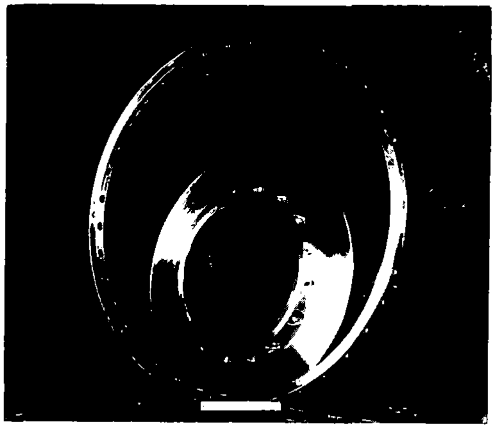

Fig.6 Ti_3Al-based alloy turbine guide plate and turbine connector ring

Status of titanium alloy casting technology in aviation industry of China

It is well known that molten titanium can react with almost all conventional refractory materials due to its very high chemical activity. Therefore its molding technology is an important key of the foundry industry. The titanium casting industry of China has successfully cast the sophisticated compressor casting case of a turboprob engine with both graphite machined mold and economic and effective rammed graphite mold.(See Fig.7) Each integral case, which consists of two castings of about 20 kg, can save over 300 welding seams and over 1000 manhour. Fig.8 shows a graphite shell mold of investment casting of a turbocharger impeller. In the eighties,the ceramic shell mold titanium investment casting technology was developed. A great number of titanium alloy casting such as the landing gear wheel hub of a hydrobomber,brake torsion tubes,the critical structural components of missile and satellite (See Fig.9 and 10) etc. have been studied and manufactured.

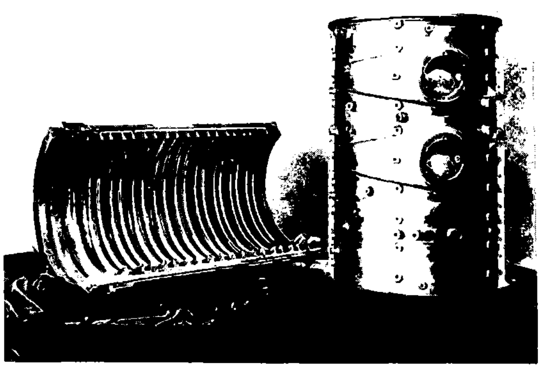

Fig.7 Titanium alloy compressor casting case of turboprob engine

Fig.8 Titanium alloy casting turbocharger impeller

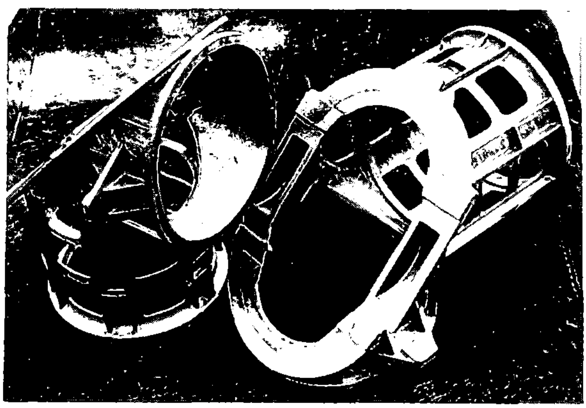

Fig.9 Man-made satellite camera cabinet of titanium alloy investment casting

ZT3 is a China made high temperature titanium cast alloy bearing rare-earth cerium capable of long term service at 500°C. Internal oxidation, which is caused by cerium in the alloy, refines beta grain boundries and improves the thermal stability and heat resistance of the alloy. Thus, ZT3 titanium cast alloy compressor cases have been srccessfully applied to new generation jet engines.

Fig.10 Helicopter impeller of titanium alloy investment casting

Conclusions

It is very important for the development of the aerospace industry to further promote research and development as well as application of titanium technology. In recent years, research areas has focused such as the effect of overloading ratio on Ti-6Al-4V alloy fatigue crack growth, estimating of service life, the influence of microstructure on low-cycle fatigue etc. Investigations of phase transformations, the dynamic rectystallization and beta brittleness have lead to developing some advanced technology, such as beta heat treatment and so on. The study of hot isostatic pressing (HIP) technology and hydrogen treatment of titanium castings plays a positive role in improving titanium casting structure and properties.

Over thirty years of experience of titanium application in the aviation industry of China has proved that it is essential to enhance the study on material service performance, such as fatigue fracture and failure analysis, to pay more attention to fundamental study on technological processes and quality control in order to guarantee that aviation products have high quality and good stability along with satifactory technical and economic effect.