



MATERIAL DEVELOPMENT OF JAPANESE AEROSPACE FASTENERS

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1. Foreword

Bolts used by the aerospace industry are very unique and are quite different from those used by other industries, including automotive and construction industries. Since aerospace crafts are aimed at “carrying people to fly over the sky”, products used in the crafts must be equipped with extremely high reliability and safety. The aerospace industry still uses the unquestionable and reliable technologies instead of trying new ones. As a key component, the bolt, playing the important role in many places and applications, shows a very strict quality requirement accordingly. As such, the diversity of materials for manufacturing bolts and the strict quality management system are not commonly seen in other industries.

2. Characteristics of Aerospace Bolt Production

Since post-war reconstruction, Japanese aviation industry has always focused on authorized production of foreign aircrafts, and even its current aviation industry cannot get rid of this

feature. For example, bolt dimensions are still in inches. Additionally, the aviation industry tremendously uses American standard bolts, such as those of Airforce Navy Aeronautical Standard (AN) or Military Standard (MS).

The most significant feature of production of aerospace bolts is strict production and quality management system based on foreign stipulated specifications. Taking procurement specification for instance, apart from Military Specification (MIL) and National Aerospace Specification (NAS), there are still exclusive specifications formulated by various crafts and engine manufacturers. These exclusive specifications specify the production methods and experimental evaluation methods of various materials in details. Especially quality management stipulates more strict equipment specification and operational methods on special process of heat treatment, surface treatment and non-destructive testing. Additionally, these special processes must obtain accreditations from various customers and the National Aerospace and Defense Contractors Accreditation Program (Nadcap).

The production is only allowed after acquiring accreditation. **Figure 1** shows the appearance of aerospace bolts.



Figure 1. Aerospace bolts

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Materials must also conform to Aerospace Material Specification (AMS) and Military Specification (MIL) that include chemical composition and production methods. In addition, these specifications stipulate the mechanical properties after heat treatment in line with material characteristics (such as tensile strength, hardness, high temperature strength, creep resistant strength, etc.). Manufacturers can be also designated as customers'



requirements. If the development of excellent materials cannot obtain the accreditations of the above-mentioned specifications after long-term, repeated tests and certifications, these excellent materials won't be applied in the aviation industry. It's noteworthy that bolt function includes especially high reliability and must be equipped with considerable performance. As such, the selection of materials for producing bolts will depend on the necessary functions accreditations needed.

As described above, aerospace bolts are strictly managed by specifications. Compared with bolts used by other industries, production of aerospace bolts is much more regulated and shows less variety. Most new technologies and new products of aerospace bolts are therefore focused on material evolution.

3. Materials for Bolts

(1) Low alloy steel

Low alloy steel, such as Ni-Cr-Mo steel, etc. has a long history usage in the part that requires high strength for aircrafts. Representative steels

include 8740 steel, 4340 steel, and so on. Tensile strength of these materials is from 125ksi (862MPa) to 180ksi (1,241MPa), strength scope is wide so that these and materials can be applied in various places and applications. Though aircrafts have a lightweight requirement, advancement of material and heat treatment technology further increases the strength to produce 4330M, H-11, 300M, etc. to be applied in high strength bolts with strength from 220ksi (1,517MPa) to 260ksi (1,793MPa). Considering the danger of hydrogen embrittlement, 4330M, H-11, 300M, etc. are mostly used in the cutting purpose, such as pins.

These low alloy steel bolts must be applied with corrosion resistant surface treatment. Additionally, cadmium plating is required based on the level of corrosion resistance. When the bolt strength is higher, hydrogen embrittlement becomes significant. In line with the required strength level, cadmium plating, cadmium fluoborate plating and low hydrogen embrittlement cadmium plating will be applied. Vacuum deposition of cadmium or cadmium titanium alloy plating will be applied to bolts of much higher strength. In addition, aluminum plating shows some good results and is expected to be equipped with anti-corrosion potential.

(2) Corrosion resistant and heat resistant steel

Except stainless steel such as the 300 series and 400 series, corrosion resistant bolts mostly use precipitation hardening stainless steel including 17-4H (SUS630) and 15-5PH. Places that require much higher strength and toughness will be applied with PH13-8Mo.

Austenitic heat resistant steel-A286 (SUH660) is equipped with excellent heat resistance and has a wide application. A286 uses a different solution temperature to produce two different strengths, 130ksi (896MPa) and 140ksi (965MPa) respectively. 130ksi can be selected if strength at high temperature is the main concern. When material

or product conducts cold processing (cold forging) and applies proper aging treatment, use of hardening can increase the strength. Based on these characteristics, drawing process is able to produce 160ksi (1,103MPa) and 200ksi (1,379MPa) in sequence. Drawing process can also produce high strength material that is separately used according to different strength requirements. Since A286 decreases the danger of hydrogen embrittlement due to the increase of strength and is classified as iron based alloy, A286 is able to reduce the cost and is expected to be adopted by high strength bolts in the future.

Taking Cobalt based super alloy MP35N as example, its strength is 260ksi at room temperature. MP35N has high fatigue strength and toughness and is equipped with excellent corrosion resistance. Though MP35N has small quantity, it can be used at the place which involves severe condition.

(3) Super heat resistant alloy

The high temperature environment within aircraft engines increases the use of super heat resistant alloys. The super heat resistant alloy used in bolts is focused on nickel based super alloy and usually adopts Waspaloy or Inconel718. Especially Inconel718 accounts for the highest percentage.

Generally by solution and aging treatment, Inconel718 is produced at the strength level of 185ksi (1,276MPa). Inconel718 and A286 are classified as the austenitic system and can increase the strength through cold processing and aging treatment. Recently more and more bolts have been produced with materials after wire drawing in the segment of 220ksi. Though Inconel718, mainly exerting its high temperature resistance, is used in engines, the use of high strength bolts in aircrafts is gradually increasing.

This article will give another characteristic cobalt based super alloy MP159 as example. MP159 is obtained to improve the heat

resistance of previously mentioned MP35N. Strength of MP159 is 260ksi at room temperature. Additionally, MP159 has a high fatigue strength and toughness and also possesses stress relaxation at high temperature. MP159 is thus applicable in engines with arduous use conditions. MP159 can use drawing process to apply hardening. Though MP159 and Waspaloy, rich in cobalt element, are equipped with excellent functions, material cost is very expensive and its poor machineability is still to be resolved.

(4) Titanium alloy

Titanium alloy is equipped with high specific strength, corrosion resistance and heat resistance. Additionally, titanium alloy has high fatigue strength, stress concentration, low sensitivity, non-magnetic, low thermal conductivity and low thermal expansion coefficient and plays an important effect to prevent the looseness of fastened bolts as well

as interference of magnetic field. As such, application of titanium alloy ranges from aircrafts to engines. Even though titanium has defects, such as high material costs and poor machineability, titanium alloy still steadily expands its applicable scope because military aircrafts are concerned about motor function and civil aircrafts demand to improve fuel efficiency and thus has the lightweight requirement. Especially application of composite materials in the aircrafts experienced a rapid development over the last few years. Since electrode potential of titanium is close to that of carbon fiber composite material, titanium alloy thus becomes the only material to join with composite material. Therefore titanium further increases its use ratio.

Most titanium alloys that are suitable for bolts are Ti-6Al-4V of α - β alloys. After solution and aging treatment, the use of 160ksi strength takes up the majority. The other practical materials include Ti-6Al-

6V-2Sn showing higher strength than Ti-6Al-4V, materials developed by Japan, and SP-700 of α - β alloys, but application cases are few. Since aircraft manufacturers wish to further reduce the weight, they strongly hope to use high strength titanium alloy bolt whose strength exceeds that of Ti-6Al-4V. However, high strength titanium alloy is not able to possess formability and fatigue strength at the same time, so high strength titanium alloy cannot be called as a competitive material for the current time.

4. Development of Aerospace Industry

In Japan, aerospace fasteners manufacturers are considered to possess steady quality, technical capability and high reliability, and many of their products are also supplied to the aerospace industry. Bolts used by the aerospace industry do not have to stipulate specifications like the aviation industry. Based

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on reliability from the related performance, most manufacturers still demand to apply aircraft specifications. According to usage, bolts have multiple shapes, and few uses standard aircraft bolts. Materials follow the aircraft specifications.

H-II A and H-II B rockets are the representatives of Japanese aerospace industry. After continuous successful launchings, rocket's reliability gradually keeps pace with global major rockets. Rockets should be improved with its launching ability and lighter weights. For example, separation bolts used in wing fairing usually adopt titanium alloy. Since the engine of LE-7A rocket must be exposed under the high temperature, it adopts super heat resistant alloys, such as Inconel718 and Waspaloy that are used in aircrafts.

In other aerospace industries, "ITOKAWA" satellite has caught much attention recently. The satellite must face two completely different environments from manufacturing, launching to arriving at the orbit. Since the satellite orbit is completely vacuum with zero gravity, satellites won't encounter any strong external force. Before launching, the satellite is still within atmosphere and must be equipped with corrosion resistance. Additionally, the satellite should be small and lightweight and use high specific strength Ti-6Al-4V material. Furthermore, the satellite carries huge precision electronic instrument, and it often uses non-magnetic austenitic stainless steel or A286.

5. Conclusions

In the future, the Japanese aerospace industry is expected to experience remarkable growth with the focus on private small planes. New aircrafts concerning about fuel efficiency and costs will be launched one after another. As such, more new technology are expected to be adopted. Since bolts must achieve

lightweight and high strength, corrosion resistant steels that are equipped with hydrogen embrittlement resistance, titanium alloy of high strength and low cost are highly expected. However, bolt production is focused on plastic processing, high strength of materials does not necessarily increase the bolt function. In such condition, materials and bolts manufacturers shall closely cooperate to develop new materials and accumulate the performance.

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